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Soil Tillage for Crop Production and Protection of the Environment

The Royal Veterinary and Agricultural University
and
The Danish Institute of Plant and Soil Science

PREFACE

The 13th Conference of the International Soil Tillage Research Organization (ISTRO) is to be held from 24 to 29 July 1994 at Aalborg, Denmark. The main theme of the Conference is "Soil Tillage for Crop Production and Protection of the Environment". By choosing this theme we wish to emphasize the importance of soil tillage in soil management aiming at the production of crops of such yield and quality that the farmers and the customers benefit. Furthermore we wish to emphasize the equal importance of soil tillage as a management tool in the long-term protection of the environment and natural resources whether these are soil quality and productivity or quality of the aquatic environment.

Soil tillage research is multidisciplinary and it is based on a number of scientific disciplines such as soil physics, soil mechanics, crop physiology, etc. Furthermore, soil tillage research could be basic, strategic or applied research although such a distinction is rather formal. Nevertheless, scientists working with soil tillage research have an important task in providing new research information on pertinent processes related to soil tillage as well as in integrating such knowledge into useful methods and strategies for economically and environmentally sustainable crop production.

The main theme of the conference is of world-wide concern. Furthermore, several basic underlying principles must be understood if enduring solutions to soil management problems are to be found. In this regard, the invited papers, which are published in full in Soil & Tillage Research Volume 30, Nos. 2-4, 1994, set the stage by reviewing research in subject areas of general interest.

The Programme Committee is most grateful to all authors of the invited review papers on the various aspects of the main theme of the Conference. Each review paper integrates and summarizes the present knowledge within the respective subthemes and combined, the review papers constitute an overall state of-the-art of the main theme of the Conference. Furthermore the review papers will provide the framework for future new approaches in soil tillage research firmly based on the theoretical knowledge of implement, soil and crop behaviour leading to more generalized practical solutions of soil management problems.

The present proceedings are the permanent record of the 205 contributed papers presented at the Conference as verbal or as poster presentations. The Organizing Committee is most grateful to all authors who have contributed volunteer papers to the Conference. Although many induvidual contributions to the Conference, quite naturally, are based on comparatively local research projects every opportunity should be taken to set such findings into a global context. It is hoped that these proceedings will serve as a valuable record of current research on the problems of Soil Tillage for Crop Production and the Protection of the Environment.

Henry E. Jensen
ISTRO President

REVIEW PAPERS

I. Håkansson (Sweden)
Soil tillage for crop production and for protection of soil and environmental quality: A Scandinavian viewpoint

T. M. Addiscott and A. R. Dexter (United Kingdom)
Tillage and crop residue management effects on losses of chemicals from soils

R. Lal (U.S.A.)
Water management in various crop production systems related to soil tillage

R. Horn, H. Taubner, M. Wuttke and T. Baumgartl (Germany)
Soil physical properties related to soil structure

F. Tardieu (France)
Growth and functioning of root systems subject to soil compaction. Towards a system with multiple signalling

R. Q. Cannell and J. D. Hawes (U.S.A.)
Trends in soil tillage practices in relation to sustainable crop production with special emphasis to temperate climates

U. D. Perdok and J. K. Kouwenhoven (The Netherlands)
Soil-tool interactions and field performance of implements

J. R. O´Callaghan (United Kingdom)
Resource utilization and economy of soil tillage in crop production systems

A. Njøs (Norway)
Future land utilization and management for sustainable crop production

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THE ORGANIZING INSTITUTIONS

The Royal Veterinary and Agricultural University
The Royal Veterinary and Agricultural University (KVL) located in the heart of Copenhagen was founded in 1858 to provide higher education in Veterinary Medicine and Agriculture. Forestry and Horticulture was added in 1863, and in 1921 Dairy Science was established. Food Science was added in 1971 and Human Nutrition in 1986. The Royal Veterinary and Agricultural University annually admits about 500 students. Totally there are more than 3250 students including more than 250 Ph. D. students. A bachelor degree can be obtained after 3 years of study. A further 2 years of study and required examination lead to a Masters degree. Individual Ph.D. study programmes of three years are offered to qualified students with an educational background equivalent at least to a Masters degree. Permanent academic staff include 45 full professors, 175 associate professors and 35 assistant professors.

The Danish Institute of Plant and Soil Science
The Danish Institute of Plant and Soil Science (DIPS) is a sector institute under the Ministry of Agriculture. It was established in 1886. For many years, the experimental work was performed at a number of experimental stations throughout the country. Organizational changes are taking place concentrating research at research centres in Jutland (Research Centre Foulum), at Funen (Aarslev) and at Sealand (Flakkebjerg) DIPS is now performing strategic and applied research. The total staff is about 600, out of which about 200 are scientists. The annual budget is about 200 mio. DKK. Research is performed in 10 departments covering all major agricultural and horticultural crops and disciplines concerning soil, water, plant nutrition, plant protection, biotechnology and post harvesting technology. DIPS participates in Ph. D. programmes cooperating with the Royal Veterinary and Agricultural University and other universities. DIPS also participate in international research programmes, including a number of EU funded projects.

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CONTROLLED TRAFFIC EFFECTS ON SOIL DENSITY, PENETRATION RESISTANCE, AND HYDRAULIC CONDUCTIVITY

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ABSTRACT

Winter wheat (Triticum aestivum L.) and grain sorghum [Sorghum bicolor (L.) Moench] were grown in rotation with limited irrigation at Bushland, Texas, from 1986 to 1992 on leveled plots. All equipment traffic was controlled. Tillage treatments were no-tillage with residues left standing (TRT-1) or shredded (TRT-2), and no-tillage after wheat and conventional tillage after sorghum (TRT-3). Soil penetration resistance (PR), bulk density (BD), and water content (WC) were determined at traffic furrow, non-traffic furrow, and row positions after the 1992 sorghum crop. In addition, hydraulic conductivity (HC), BD, and PR were determined on cores from those positions in the laboratory. Under field conditions, mean BD and PR were greatest in the traffic furrow; tillage had no effect on BD or PR. For laboratory cores, mean BD and PR were greatest for the traffic furrow and least for the non-traffic furrow. Tillage did not affect PR. Differences in HC due to tillage, sampling position, and sampling depth were not significant at the P = 0.05 level. These results show the importance of controlling traffic when no-tillage crop production systems are used.

INTRODUCTION

Conservation tillage is widely promoted because of the erosion control benefits that result from retaining crop residues on the soil surface. Surface residues, however, also enhance soil water conservation (1,2,3), which is highly important for successful crop production under non-irrigated conditions in semiarid regions. No-tillage results in greatest retention of residues, but concern often is expressed regarding the potential for the development of unfavorable soil physical conditions when it is used because the soil is not loosened by tillage. No-tillage had no consistent beneficial or detrimental effects on physical conditions of Pullman clay loam (Torrertic Paleustoll) under non-irrigated conditions (4). However, the potential for development of localized zones of unfavorable conditions seemed likely when the soil is irrigated and when all cultural operations are restricted to specified areas (controlled traffic). The objectives of this study were to compare the effects of controlled traffic in no-tillage and reduced-tillage plots on bulk density, penetration resistance, and hydraulic conductivity of soil used for winter wheat and grain sorghum production under limited irrigation conditions. Soil organic matter concentration was determined also.

METHODS AND MATERIALS

The study was conducted at the USDA Conservation and Production Research Laboratory, Bushland, Texas (USA), on Pullman clay loam (fine, mixed, thermic Torrertic Paleustoll) on which winter wheat and grain sorghum were grown in rotation from 1986 to 1992. Plots were leveled before starting the study, but plowed to form ridges at 1.0-m intervals for the study. Wheat drill row spacing was 0.25 m and sorghum row spacing was 1 m (one row per ridge). Crops were irrigated by flooding the plots when major plant water stress developed. Treatments, replicated three times, were no-tillage with residues left standing (TRT-1), no-tillage with residues shredded (TRT-2), and no-tillage after wheat and conventional tillage after sorghum (residues incorporated) (TRT-3). Complete details of the rotation study are given in Unger (5).

All equipment traffic on plots was restricted to specified furrows throughout the 6-year study. After sorghum harvest in 1992, various determinations were made under field and laboratory conditions. Sampling was done at traffic furrow, non-traffic furrow, and row positions. Bulk density (BD) was determined from 5.4-cm-diam. cores taken to a 50-cm depth at five locations for each position. Cores were separated into 10-cm-long segments, weighed, oven-dried at 105°C, and weighed again to determine water content. Penetration resistance (PR) was determined to a 50-cm depth at 10 locations at each position using a 12.8-mm diam. cone on a recording penetrometer (Bush Soil Penetrometer SP1000, Findlay Irvine Ltd., Penicuik, Midlothian EH26 9BU, Scotland)[1]. Values at 5-, 15-, 25-, 35-, and 45-cm depths were used to analyze the PR data statistically.

For laboratory determinations, cores were obtained from each furrow position at the surface and at a 10-cm depth. For row position cores, surface soil was removed so that the sampling level was the same as for furrow positions. The cores, 5.4 cm diam. and 3.5 cm long, were kept in plastic bags and refrigerated until determining hydraulic conductivity (HC) on eight cores from each position by the procedure of Klute (6). Conductivities were determined for 0- to 1-, 1- to 3-, and 3- to 6-hour periods. The data were scaled by the procedure of Warrick et al. (7) before statistical analysis. After determining HC, 10 measurements with a penetrometer (4.76-mm diam. flat point, Model 719-5MRP, John Chatillon & Sons, Kew Garden, NY 11415) were made on each core. Cores were dried at 60°C and weighed before calculating bulk density. The cores were then ground before determining organic matter concentration (OMC) by the modified Walkley-Black procedure (8).

Data were analyzed by the analysis of variance technique (9) and, when the F-test showed statistical significance at the 5% level (P = 0.05), the protected least significant difference (Prot. LSD) procedure was used to separate means.

RESULTS AND DISCUSSION

Significance levels of F values, as determined by the analysis of variance technique, are given in Table 1. No variable [sampling depth (D), sampling position (P), or tillage method (T)] had a significant effect on soil HC. Except for OM concentration that was affected only by the D variable, all remaining factors were significantly affected by the D and P variables and the D x P interaction. No P x T x D interaction was significant and the values are not shown. Because tillage methods did not significantly affect any of the measured factors, except BD of laboratory cores, data given in Table 2 are for position and depth averaged across tillage methods. Effects of tillage on BD of laboratory cores are given in the text.

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[1] Names are necessary to report factually on available data: however, the USDA neither guarantees nor warrants the standard of the product, and the use of the name by USDA implies no approval of the product to the exclusion of others that may also be suitable.

Table 1. Significance levels of F values for soil variables as influenced by sampling depth (D), sampling position (P), and tillage treatment (T).

Soil variable	Significance level of F value for					
	D	P	P x D	T	T x D	P x T
Field determinations						
Bulk density	.0005	.0025	.0002	.1682	.4751	.7085
Penetration resistance	.0001	.0001	.0001	.1494	.8813	.2721
Water content	.0002	.0012	.0006	.5593	.9875	.4303
Lab determinations						
Hydraulic conductivity						
0 – 1 hour	.1889	.1638	.2977	.3243	.2008	.4661
1 – 3 hour	.1358	.1295	.4131	.2291	.1969	.2328
3 – 6 hour	.1778	.1691	.6170	.2711	.2230	.2725
Penetration resistance	.0016	.0079	.3272	.2011	.0767	.3056
Organic matter conc.	.0425	.2672	.5024	.2067	.1529	.6149
Bulk density	.0059	.0012	.0016	.0203	.0378	.5437

Large core or field determinations

Mean soil BD was greatest at the traffic furrow and similar at the non-traffic furrow and row positions for all tillage methods. Although significant, mean differences were not large because differences among positions at individual depths were significant only for the 0- to 10-cm depth increment. At this depth, BD was greatest in the traffic furrow because of repeated traffic and least in the non-traffic furrow because of no traffic. Greater BD at the row position than at the non-traffic furrow position at the 0- to 10-cm depth is attributed to some soil compression during crop planting, especially sorghum that was planted on ridges where the row sampling occurred. At other depths, differences among positions were not significant. Except for the same BDs at 10 to 20 and 20 to 30 cm, BD increased with depth, which is typical for Pullman soil (10).

Mean water contents (WCs) were similar for both furrow positions, but both were greater than for the row position. Differences occurred mainly in the two upper increments where WC for the row position was lowest. Lower WC in the row possibly resulted from greater water use by sorghum. Decreasing WCs with depth suggest that late growing-season or post-harvest rainfall may have partially replenished the soil water supply near the surface.

Penetration resistance at 5 cm was greatest in the traffic furrow and least in the non-traffic furrow. At 15 cm, PR was greater in the traffic furrow than at other positions and, at 25 cm, it was greater at both furrow positions than at the row position. Differences at 35 cm were not significant, but PR was less at the row position than in the non-traffic furrow at 45 cm. Greater PRs at 5, 15, and 25 cm and the mean for the traffic furrow resulted from traffic being confined to that position during the 6-year study. Greater PR at 5 cm for the row than for the non-traffic furrow is attributed to greater soil compression during crop planting, as mentioned previously. Reason for the difference at 45 cm is not apparent. Mean PR was greatest for the traffic furrow position because of repeated traffic. It was least for the row position because no traffic occurred there and possibly because of greater root activity. Mean PR increases with depth, in a general way, followed mean BD increases and water content (WC) decreases with depth. Based on multiple regression analysis, PR was related to BD and WC as given by:

Table 2. Sampling position and depth effects on soil conditions in a controlled-traffic study for wheat and grain sorghum production, Bushland, Texas (U.S.A.)

	Position			
Depth	Traffic	Non-Traffic	Row	Mean
cm	Bulk density — g/cm³ (field)			
0 - 10	1.52	1.40	1.45	1.46
10 - 20	1.51	1.52	1.50	1.51
20 - 30	1.51	1.50	1.51	1.51
30 - 40	1.54	1.55	1.53	1.54
40 - 50	1.57	1.55	1.57	1.56
Mean	1.53	1.50	1.51	
LSD (0.05): Depth (D) — 0.031, Position (P) — 0.014, P x D — 0.035				
	Water content — % by volume (field)			
0 - 10	40.5	41.2	38.2	40.0
10 - 20	38.9	40.1	38.3	39.1
20 - 30	37.3	37.3	37.4	37.3
30 - 40	36.5	36.9	36.7	36.7
40 - 50	35.8	35.4	36.0	35.7
Mean	37.8	38.2	37.3	
LSD (0.05): Depth (D) — 1.2, Position (P) — 0.43, D x P — 1.06				
	Penetration resistance — MPa (field)			
5	0.62	0.30	0.47	0.46
15	0.88	0.56	0.64	0.69
25	1.30	1.23	1.04	1.19
35	1.58	1.65	1.63	1.53
45	1.79	1.89	1.69	1.79
Mean	1.23	1.13	1.04	
LSD (0.05): Depth (D) — 0.07, Position (P) — 0.07, D x P — 0.16				
	Bulk density — g/cm³ (laboratory)			
0 - 3.5	1.53	1.33	1.45	1.44
10.0 - 13.5	1.60	1.59	1.56	1.58
Mean	1.57	1.46	1.51	
LSD (0.05): Depth (D) — 0.05, Position (P) — 0.04, D x P — 0.06				
	Organic matter concentration — g/kg (laboratory)			
0 - 3.5	18.3	17.2	17.1	17.6
10.0 - 13.5	14.3	13.8	14.2	14.1
Mean	16.3	15.5	15.7	
LSD (0.05): Depth (D) — 3.2, Position (P) — NS, D x P — NS				
	Penetration resistance — MPa (laboratory)			
0 - 3.5	0.37	0.17	0.28	0.27
10.0 - 13.5	0.43	0.33	0.46	0.41
Mean	0.40	0.25	0.37	
LSD (0.05): Depth (D) — 0.02, Position (P) — 0.08, D x P — 0.12				

$$PR = 3.125 + 3.960\ BD - 0.211\ WC\ (R^2 = 0.886)$$

The significance level of the F value was 0.037 for the BD effect and 0.0003 for the WC effect, suggesting that the relatively slight decreases in WC with depth had a greater effect on PR increases with depth than the increases in BD with depth.

Laboratory determinations

Differences in HC due to tillage methods, sampling positions, and sampling depths were not significant at the 0.05 level, but were significant at levels between 0.13 and 0.19 for depths and positions and between 0.22 and 0.33 for tillage (Table 1). For all periods (0 to 1, 1 to 3, and 3 to 6 hours), HCs were greater for TRT-3 than for TRT-1 and TRT-2, for which they were similar; greatest for the row position and least for the traffic furrow position; and greater for the 0- to 3.5-cm (upper) and than for the 10.0- to 13.5-cm (lower) depth (data not shown). These trends were, in a general way, inversely related to trends in PR and BD of the cores, as discussed in following paragraphs and shown in Table 2.

Soil BD was lower for the 0- to 3.5-cm depth than for the 10.0- to 13.5-cm depth at all positions, which resulted in a lower mean for the 0- to 3.5-cm depth. For that depth, BD was greatest for the traffic furrow and least for the non-traffic furrow. For the lower depth, BDs were similar for all positions. Mean BD was greatest for the traffic furrow and least for the non-traffic furrow because of differences for the upper depth, with these results reflecting the influence of traffic control during the 6-year study period. Mean BDs were 1.51, 1.55, and 1.48 g/cm^3 for TRT-1, TRT-2, and TRT-3, respectively, with a difference of 0.043 needed for statistical significance. The lower BD for TRT-3 resulted from soil loosening by tillage after sorghum harvest in previous years of the study. For TRT-1 and TRT-2, the soil was not loosened during the 6-year study period. Soil loosening also contributed to the significant tillage x depth interaction effect (Table 1). Because of soil loosening at previous times during the rotation study, mean BD for the upper depth of TRT-3 was lower than for the other treatments, especially for non-traffic furrow and row positions (data not shown). Means were similar for all treatments for the lower depth.

Soil OMC was significantly greater for the upper than for the lower sampling depth. A sharp decline in OMC with depth is typical for Pullman clay loam (10), and especially under no-tillage conditions (11). Differences in OMC due to tillage methods and sampling positions were not significant, but OMC tended to be greater on TRT-1 and TRT-2 (only no-tillage) plots than in TRT-3 plots (data not shown) and greater for the traffic furrow than for the other positions. The trend due to positions probably resulted from the greater density of the traffic furrow soil that may have slowed microbiological activity and, hence, breakdown of surface residues and incorporation of residual organic materials with soil.

Soil PRs were similar for both depths at the traffic furrow position. In the non-traffic furrow and row positions, the lower depth had a greater PR, resulting in mean PR across all positions being greatest for the lower depth. For the upper depth, PR was greater in the traffic furrow due to repeated traffic than in the non-traffic furrow that received no traffic during the 6-year study. Although not significant at the 0.05 level, traffic contributed to the trend toward the greater PR in the traffic furrow as compared with that in the non-traffic furrow for the lower depth. However, at that depth, PRs for traffic furrow and row positions were similar, indicating that traffic alone does not influence differences in PR. This is indicated also by the means for non-traffic furrow and row positions, which differed significantly. Greater PR for the row position, which occurred also under field conditions, is attributed to soil compression at crop planting that was previously mentioned. Soil PR was significantly related to BD, but not to soil OMC, as determined by regression analysis. The relationship is given by:

$$PR = -1.020 + 0.901\ BD\ (R^2 = 0.774)$$

Soil WCs were uniformly high when PRs were measured and, hence, were not considered to be a factor that affected PR of the cores.

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CHARACTERIZING MACROPORE CONTINUITY AND AERATION IN FINE SANDY LOAMS IN TILLAGE STUDIES

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ABSTRACT

Tillage studies were conducted over several years on fine sandy loams (Podzols) with winter wheat (*Triticum aestivum* L.) and silage corn (*Zea mays* L.), under the cool, humid climate of Prince Edward Island. Moldboard ploughing and direct drilling were evaluated in different tillage rotations for their effect on soil physical properties, specifically soil aeration and the structure of macropore space. Sequential measurements on soil cores equilibrated at 6 kPa tension for macropore volume, air permeability at low air pressure (0.25 kPa), and oxygen diffusion rate (ODR) at 0.65 mV were used to characterize the soil physical condition. The quotient of air permeability and macropore volume proved to be a useful measure of pore continuity. Differences in tillage-induced soil physical properties were used to evaluate both tillage rotation and time of tillage.

INTRODUCTION

In humid climates, characterizing the soil structural condition is important to assess the feasibility and potential for adoption of conservation tillage practices. Macroporosity is a useful index to gauge soil response to different tillage systems (1). In well drained soils at 'field capacity' moisture level, macropore volume is approximately equal to air-filled porosity. Knowledge of both air-filled porosity and water-filled porosity (relative saturation) is usually required to characterize water infiltration and soil biological environment in humid soil moisture regimes (2). The continuity of soil macropores is an important aspect of soil physical quality as it relates the ability of the soil pore space to transmit water or air. Recently, air permeability of macropore space has been used to assess macropore continuity in field studies (3, 4).

The combination of relatively high precipitation and non-plastic soil type increases the propensity for excessive soil compaction and reduced macroporosity under reduced tillage in Prince Edward Island (5). Strategies to remove climatic and soil impediments for adoption of conservation tillage include use of 'tillage timing' and 'rotational tillage'. The former circumvents the propensity for soil compaction by shifting the time of tillage event (4), while the latter employs tillage inputs on an opportunistic basis, or at specific times within a crop rotation, to remove adverse soil conditions.

The objectives of this study were: a) to characterize the soil physical condition under two conservation tillage systems in Prince Edward Island; and b) to assess various indices of pore continuity.

MATERIALS AND METHODS

Two tillage experiments were established near Charlottetown, Prince Edward Island: a) two year study (1985-1986) with winter wheat (*Triticum aestivum* L.), and b) six year study (1983-1988) with silage corn (*Zea mays* L.). The soil type for both experiments was a fine sandy loam (7-10% clay, 28-31% silt, and 40-50% fine sand).

Soil tillage treatments

In the winter wheat study three tillage treatments were employed: a) mouldboard ploughing (25 cm) with a furrow press, b) shallow tillage (two passes of a rotary harrow at 10 cm), and c) direct drilling. Winter wheat was seeded in September each year. All treatments retained the straw (chopped and spread) and stubble from the previous crop. The statistical design of the experiment was a randomized complete block with six replicates (each 6 × 15 m).

Three tillage treatments were sampled in the silage corn study: a) mouldboard ploughing (20 cm), b) direct planting, and c) direct planted corn / mouldboard ploughed barley (*Hordeum vulgare* L.). The latter was a continuous tillage rotation where ploughing followed direct planting. Corn was planted in late May each year. Both corn and barley stubble were retained each year. The statistical design of the experiment was a randomized complete block with four replicates (each 7 × 40 m).

Soil sampling and analysis

Soil cores (8 cm i.d. × 8 cm) were obtained from three soil depths (0-8, 8-16, 16-24 cm) in the spring following the termination of each experiment. Three cores were taken at each depth, per replicate, when the soil was near field capacity to prevent soil shattering. For the corn study, cores were obtained from both the 'in-row' and 'between-row' position and analyzed separately. Cores were taken from the direct planted corn phase in the rotational tillage treatment. The cores were wrapped in plastic and stored at 4°C.

Soil water desorption using a tension table with a tension medium of glass beads (30 µm, diameter), at a tension of 6 kPa, was employed to provide an estimate of macropore volume (equivalent pore diameter > 50 µm) (6). The cores were dried at 105°C to determine dry bulk density. Air permeability was determined on the soil cores, equilibrated at 6 kPa tension, using a low (to reduce turbulent flow) constant air pressure of 0.25 kPa to characterize macropore continuity (4). An index of the latter was calculated by dividing air permeability by the fractional macropore volume (3). The oxygen diffusion rate (ODR) was measured in the cores, immediately after the air permeability measurement, using platinum electrodes and an effective voltage of 0.65 mV (4).

RESULTS AND DISCUSSION

Winter wheat study

Bulk density and macropore volumes were significantly greater in the ploughed treatment than the other two systems (Table 1). In all cases, however, the porosity values were well above the critical level (ie. 12-14%) needed to provide adequate air-filled pore space, under a humid moisture regime, in these soil types (2). Both air permeability and ODR did not differ significantly among tillage treatments or soil depth. The ODR values were above the critical range (40-50 µg $m^{-2} s^{-1}$) required for wheat root growth (7).

Table 1 Soil physical condition of the tillage zone after 2 years under three reduced tillage systems for winter wheat in Prince Edward Island.

Tillage treatments	Dry bulk density (Mg m^{-3})	Macropore (% soil volume)	Air permeability (µm^2)	Pore continuity	ODR (µg $m^{-2}s^{-1}$)
			0 - 8 cm		
Mouldboard plough	1.12	20.4	108.1	530	59
Shallow tillage	1.19	16.8	110.9	660	60
Direct drill	1.17	17.8	97.9	550	58
Significance level	0.007	0.042	0.226	0.030	0.991
			8 - 16 cm		
Mouldboard plough	1.11	22.2	102.1	460	64
Shallow tillage	1.22	16.3	94.5	580	62
Direct drill	1.24	14.0	89.6	640	66
Significance level	<0.001	<0.001	0.235	0.009	0.665
			16 - 24 cm		
Mouldboard plough	1.14	20.5	86.1	420	70
Shallow tillage	1.28	14.7	69.1	470	64
Direct drill	1.28	15.5	110.1	710	60
Significance level	<0.001	<0.001	0.176	0.010	0.370

Conducting tillage and seeding under drier conditions in the autumn proved beneficial for maintaining an optimum soil condition. In contrast, moister soil in the spring usually increases the probability for excessive soil compaction under direct drilling (2, 5).

Silage corn study

Six years of continuous direct planted corn resulted in the formation of an adverse soil physical condition below the 8 cm soil depth for both the 'in-row' position (Table 2) and the 'between row' position (data not shown). The slightly greater deterioration of the soil condition for the 'between row' position was related to the degree of vehicular traffic. Continuous direct planting reduced soil macropore volume below 10%. This was also reflected in dry bulk density exceeding 1.3 Mg m^{-3}. Values for ODR were also relatively low under direct planting. In contrast, ploughing provided an optimum soil physical condition throughout the tillage zone. Use of rotational tillage tended to result in an intermediate soil physical condition, between continuous direct planting and ploughing. Generally, rotational tillage maintained an acceptable soil condition.

Table 2 Soil physical condition of the tillage zone in the row after 6 years under three tillage systems tillage systems for silage corn in Prince Edward Island.

Tillage treatments	Dry bulk density (Mg m^{-3})	Macropore (% soil volume)	Air permeability (μm^2)	Pore continuity	ODR ($\mu g\ m^{-2} s^{-1}$)
			0 - 8 cm		
Mouldboard plough	1.09	18.2	80.3	447	89.5
Direct plant	1.14	12.7	56.4	478	47.2
Rotational tillage	1.15	13.8	56.0	410	74.7
Significance level	0.120	0.009	0.006	0.626	0.079
			8 - 16 cm		
Mouldboard plough	1.17	14.9	47.2	323	67.1
Direct plant	1.32	8.8	30.0	335	53.3
Rotational tillage	1.25	13.1	31.7	247	58.3
Significance level	<0.001	<0.001	0.199	0.531	0.103
			16 - 24 cm		
Mouldboard plough	1.23	12.6	16.2	139	65.6
Direct plant	1.35	7.0	17.2	243	39.6
Rotational tillage	1.28	10.9	23.6	213	51.0
Significance level	<0.001	0.002	0.188	0.104	0.005

Pore continuity measurements

The ratio of air permeability (μm^2) and fractional macropore volume (% soil volume × 0.01) provides a relative comparisón of the organization of the macropore space (3). In addition, the ODR values provide a useful index of soil aeration, as they increase with an increase in macropore volume and decrease as soil compaction increases (7). The derived pore continuity value indicated significant differences among tillage treatments in the winter wheat experiment (Table 1). The direct drilling treatment had a greater pore continuity value, over the 8-24 cm soil depth, than the ploughed or shallow tillage treatments. Evidently, the large volume of macropores under ploughing were less efficient in conducting air than the smaller volume of macropores under direct drilling. Under ploughing many of the tillage-induced macropores would be isolated or non-functional in regard to air or water transmission (2). In the corn experiment, pore continuity relationships followed a similar trend as that found for the winter wheat study (Table 2). However, lower values for both macropore volume and air permeability significantly reduced the values for pore continuity over the 8-24 cm soil depth.

Regression analysis, based on the replicated data from both experiments showed relatively close linear relationships between pore continuity and macropore volume ($r^2 = 0.61$, $n = 27$, $p < 0.001$). Based on the above relationship, the critical macroporosity of 12% (% soil volume) established for these soils corresponds to a pore continuity value of 350. A close linear relationship was also found between ODR and macropore volume ($r^2 = 0.64$, $n = 27$, $p < 0.001$). In this relationship, the above critical macroporosity corresponds to an ODR value of 57 $\mu g\ m^{-2}\ s^{-1}$. For the direct planted treatments alone, a very close linear relationship occurred between pore continuity and macropore volume ($r^2 = 0.89$, $n = 9$, $p = 0.01$). Furthermore, the slope of the regression equation was twice as steep as that found for the total data indicating that although macropore space is diminished under direct drilling, compared to ploughing, the efficiency in regard to pore continuity is increased. For example, a macropore volume of 8% (% soil volume) under direct drilling was associated with a pore continuity value of 350. However, although soil permeability can be adequately maintained at a relatively lower macropore volume under direct drilling, compared to ploughing, the need to ensure adequate soil aeration (ie. ODR value) in humid soil conditions would necessitate a macropore volume requirement above 8%.

CONCLUSIONS

Air permeability and macroporosity measurements on soil cores were useful methods to characterize pore continuity, while ODR provided an overall indicator of soil aeration. Use of 'tillage timing' for small grains and 'rotational tillage' for silage corn were successful strategies that allowed adoption, or partial adoption, of soil conservation practices while sustaining soil physical quality.

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DECOMPOSITION OF PLANT RESIDUES IN SOILS UNDER DIFFERENT MANAGEMENT

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ABSTRACT

Understanding the fate of crop residues is important for determining the extent to which soil tillage affects the storage of carbon and the recycling of nutrients in soils. The decomposition of maize and alfalfa residues and maple leaves was monitored over 582 d in a field study. The residues were placed in litterbags at the surface of no-tillage, moldboard plowed and forest soils, and buried in moldboard plowed and forest soils. The quality of the residue, as measured by the initial C:N ratio of the residue, played an important role in the rate and extent of decomposition. The rate of decomposition was highest for the alfalfa residues, lowest for the maize residues and intermediate for tree leaves. The per cent C remaining in surface-placed alfalfa residues was similar for all sites, but maize residues and tree leaves lost more C to decomposition in plowed soils. For all residue types, decomposition was more rapid and extensive for residue buried in plowed soil than for those buried in forest soil. Differences in decomposition between buried residues were attributed to differences in soil temperature and moisture.

INTRODUCTION

Soil organic matter is a major terrestial pool for C, N, P and S and the cycling and availability of these elements is altered by soil microbial activity. Tillage practices affect soil environmental factors, such as temperature, water content, aeration, and nutrient availability, which regulate plant growth and microbial activity. No-tillage tends to induce cooler, wetter, more compact and less aerobic soil environments and increases the stratification of organic matter within the soil profile. Hence the decomposition of organic matter and the consequent storage of C and recycling of nutrients may be significantly altered in no-tillage systems. Also, the increased amounts of residues which accumulate on the surface of no-tillage soils play an important role in disease, insect and weed control, soil warming in the spring, and the uptake of native and applied nutrients. Factors which control the rate of residue decomposition include the nutrient composition and placement of residue as well as soil temperature and moisture conditions. There is limited information on residue decomposition in soils under different tillage systems and the ohjective of this study was to determine the influence of soil management and litter placement on the decomposition of different types of plant residue.

MATERIALS AND METHODS

The soils on which the study was conducted are classified as Orthic Humic Gleysols, which are poorly drained in their natural state. The forest site had been used as a woodlot, but the soils had not been cultivated. Tile drains were installed on the cropped site about 25 yr ago and maize (*Zea mays* L.) had been grown continuously since that time. Four yr prior to this study, no-tillage and conventional tillage plots were established to evaluate soil structural changes. Tillage operations on the conventional plots include moldboard plowing in the autumn and secondary tillage with an off-set disk before planting in the spring. At the end of the season the grain was removed from the no-tillage and plowed plots with a combine harvester, and all corn residues were returned to the soil.

Maize and alfalfa residue and maple leaves (Table 1) were placed in fiberglass mesh bags (with openings of 1 mm by 1 mm and inside dimensions of 15 cm by 10 cm) at the surface of no-tillage, moldboard plowed and forest soils and at 15-cm depth in moldboard plowed and forest soils. The amount of residue placed in each bag was equivalent to the average amount of residue per unit area returned to the soil each autumn (*i.e.*, 7 Mg maize residue and 3.5 Mg alfalfa or tree leaves ha^{-1}). The bags were placed in the field on October 1991, and six replicates of each residue type were retrieved at 0, 34, 193, 231, 306, 387, 582 d after placement; soil temperature was monitored continuously at the surface and 15 cm depth. After removal, the residue bags were dried at 70° C and the residue removed, weighed and ground for total organic carbon (C) and ash contents. The weight and composition of the residues were determined on an ash-free basis to minimize the effects of any soil contamination. Decomposition of the residues in litterbags was assumed to follow first-order kinetics. Estimates of the decomposition rate coefficient, *k*, were obtained from the equation $A_t = A_0e^{-kt}$ where A_t = the per cent residue C remaining at time, *t*; A_0 = 100%, the percent C at the start of the field incubation.

Table 1. Initial organic carbon, nitrogen and C:N ratio of the plant residues.

Residue	Organic C mg g^{-1}	N mg g^{-1}	C:N ratio
Alfalfa	453	26	18
Tree leaves	475	14	34
Maize	440	8	55

RESULTS AND DISCUSSION

Surface-placed residues

The rate of decomposition was greatest for alfalfa residue, lowest for maize residue and intermediate for tree leaves (Table 2). Generally the extent of decomposition (*i.e.* the per cent of C remaining in the litterbags at 582 d in the field) followed the same trend. These trends are a reflection of the the N content of the residue (Table 1). The alfalfa residue had a relatively high N content and narrow C:N ratio and thus decomposed more quickly than the maize residue. A C:N ratio of approximately 25 is required for plant residue decomposition without tie-up (immobilization) of N, which will slow decompositon.

The site at which residues were placed appears to have had an effect on the extent of decomposition of the surface-placed residues. At 582 d the forest soil had the largest amount

Table 2. The decay rate constants, coefficients of determination for a first-order model of decomposition and % C remaining at 582 d after placement of three residue types located at different positions and sites.

RESIDUE TYPE	SITE	DECAY RATE (k, day^{-1})	r^2	C REMAINING (%)
		Surface-placed residues		
ALFALFA	FOREST	0.0033	.83	25 ± 3†
	NO-TILL	0.0036	.90	17 ± 5
	PLOWED	0.0035	.96	20 ± 3
MAIZE	FOREST	0.0017	.95	42 ± 12
	NO-TILL	0.0016	.92	41 ± 3
	PLOWED	0.0021	.88	27 ± 7
TREE LEAVES	FOREST	0.0022	.93	32 ± 10
	NO-TILL	0.0024	.92	19 ± 6
	PLOWED	0.0028	.93	13 ± 4
		Buried residues		
ALFALFA	FOREST	0.0025	.35	41 ± 6
	PLOWED	0.0051	.76	17 ± 2
MAIZE	FOREST	0.0016	.93	48 ± 7
	PLOWED	0.0033	.89	17 ± 3
TREE LEAVES	FOREST	0.0016	.86	32 ± 5
	PLOWED	0.0032	.87	19 ± 4

† Mean ± Standard Deviation

of C remaining, and the plowed soil had the smallest amounts remaining for maize and tree leaves. Approximately 27% of the C in the maize residues remained in the plowed soils whereas about 42% remained in the forest and no-tillage soils (Fig. 1a & Table 2). The larger amounts of C lost in plowed soils may be related to differences observed in the surface soil temperatures at each site. Figure 2a shows the difference between the temperatures at the surface of the forest and plowed soils, as well as between the forest and the no-tillage soils. The surface soil temperature on plowed soils was higher than either the no-tillage or forest soil during the spring and early summer (between 180 and 240 d) when microbial activity and decomposition processes are at a maximum. The temperatures on plowed soils were lower than on the no-tillage or forest soils for the late autumn to early spring when the soils were frozen. Later in the growing season, between 240 and 300 d, the plowed soil temperature was between 10 and 20°C, and the forest was always at least 5°C cooler. The no-tillage surface soil temperature was similar or higher than that of the plowed soil later in the season, when microbial activity may have been lower due to hot, dry conditions.

Buried residues

The rate of decomposition was higher for buried alfalfa residues than for maize residues or tree leaves (Table 2), again reflecting the labile nature of alfalfa. This is particularly evident in the observation that between 40 and 50% of the C in alfalfa residues (data not shown) was lost within 34 d of burial, whereas only 10 to 25 % was lost from the maize residues during this period (Fig. 1b). The extent of decomposition was similar for all residue types buried at the different sites. For example, between 17 and 19% of the C remained in all three residues in the plowed soils.

The site at which the residues were buried affceted the rate and extent of decomposition of residues, and plowed soils were more conducive to decompositon processes than forest soil. For example, about 17% of the buried maize residue C remained at 582 d in the moldboard plowed soil, whereas 48% remained in the forest soil (Fig. 1b & Table 2). Furthermore, the rate of decomposition in the buried maize residue was two times higher in the plowed soil compared to the forest soil. The differences in decomposition between the two sites are partly linked to differences in temperature (Fig. 2b). The plowed soil at 15-cm depth was consistently warmer (up to 7°C) than the forest soil between spring thaw and late summer (between 200 and 300 d after placement). The differences in decomposition between the forest and plowed soils may also be related to different moisture regimes. The moisture content and aeration status of the forest and plowed soils are quite different. The tile-drained, plowed site probably has a lower moisture content and better aeration than the forest soil; consequently, the relatively poor drainage in the forest soil would promote anaerobic conditions, hindering the decomposition of the residue.

Buried vs. surface-placed residues
For each residue type, the rate of decomposition was always greater for buried residues than for surface-placed residues in the plowed soil (Table 2), indicating that more intimate contact of the residue and the soil enhanced the speed of decomposition. However, soil temperature and moisture also play a crucial role in the decomposition of the residues and may override the placement effects on residue decomposition. This is illustrated in the differences observed between surface-placed and buried residues in the forest soil. The amounts and rates (Fig. 1 & Table 2) of C lost in surface-placed residues were consistently greater than those lost in the buried residue at the forest site. This retarded decomposition may be linked to unfavourable soil environmental conditions. The plowed soil temperatures are significantly higher during the spring and summer (Fig 2b), when soil microbial activity is highest and the aeration status of the plowed soil is better than that of the forest soil.

CONCLUSIONS

Preliminary analyses of plant residue decay indicated that decomposition rates of alfalfa residue exceeded those for maple leaves, but the extent of decomposition after 582 d was similar for both residues. Relatively slow decomposition rates for maize residue may reflect its poorer quality (*i.e.*, wider C:N ratio). The site where the residues were placed also influenced decomposition. Comparatively low rates of decay in the forest were attributed to low temperatures and saturated soils in the spring. Decomposition rates at the surfaces of no-tillage and plowed soils were similar for alfalfa residue, but maize residue and tree leaves underwent greater decomposition in plowed soils. In the plowed soil, decomposition rates were greater for buried than for surface-placed residues, but the converse occurred in the forest soil, where unfavourable soil environmental conditions may have overcome the placement effects on residue decomposition.

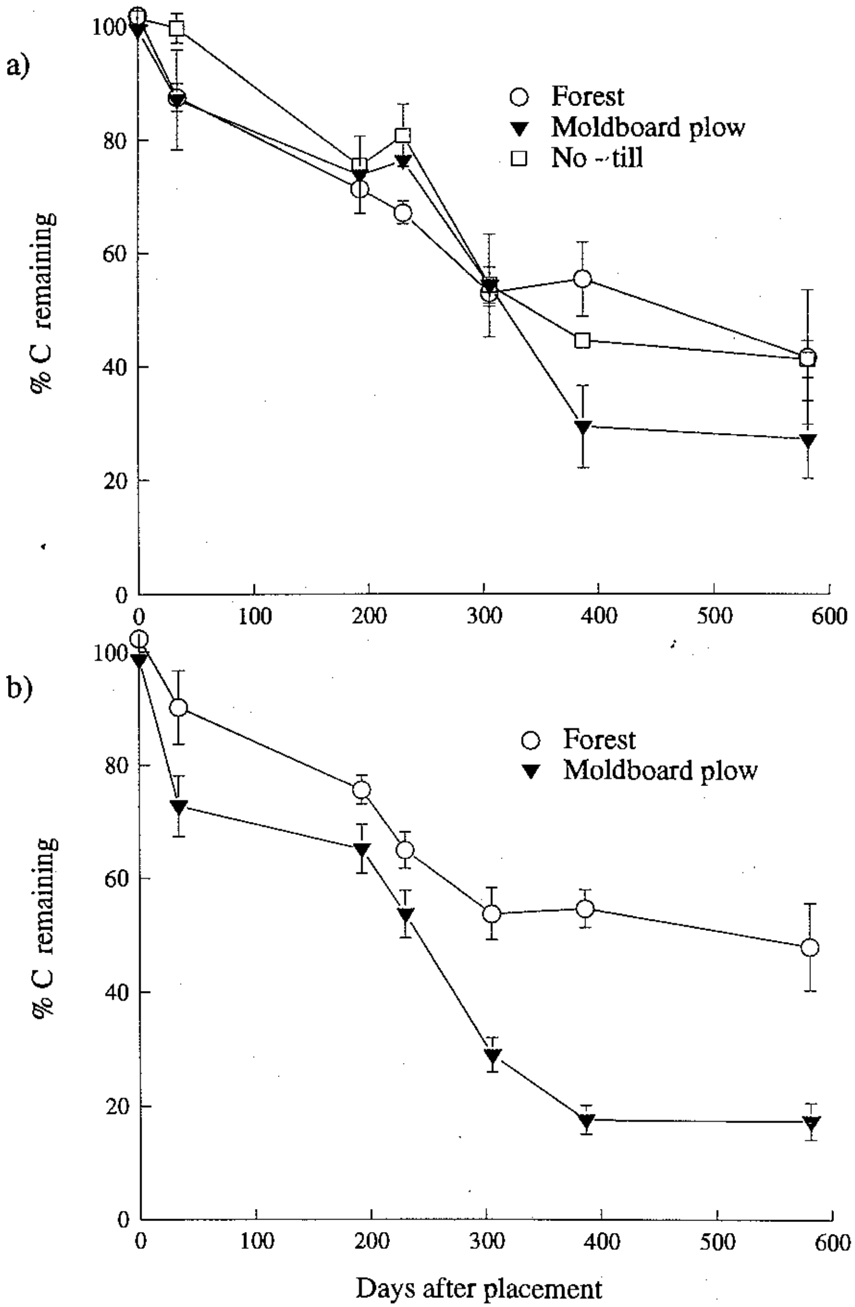

Figure 1. Per cent C remaining in litterbags containing maize residues a) on the surface, or b) buried in forest, no-tillage, and moldboard plowed soils.

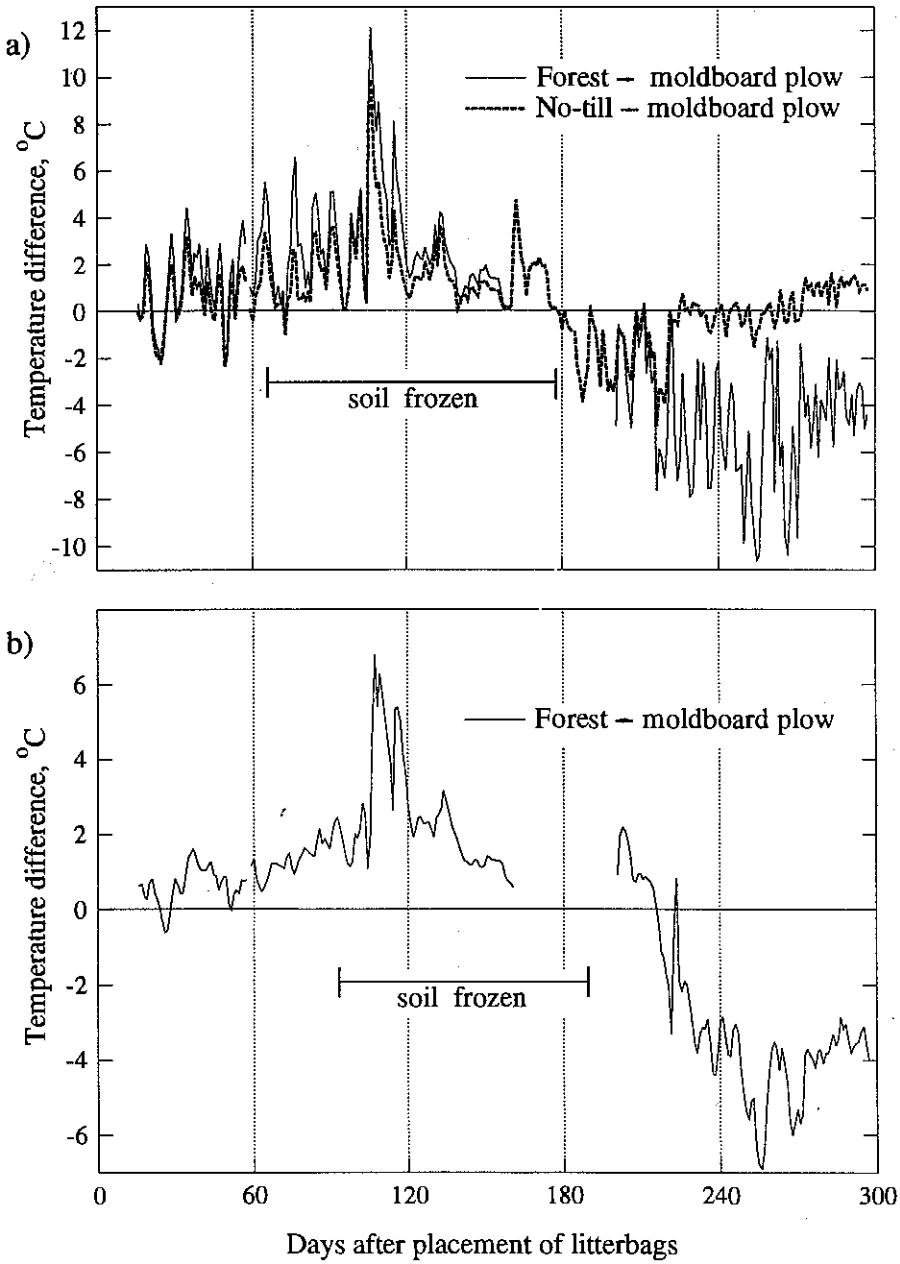

Figure 2. Differences in soil temperatures, measured over time a) on the surface in forest, no-tillage, and moldboard plowed soil, or b) buried 15 cm in forest and moldboard plowed soils. Calculations are made from means of hourly measurements.

EFFECTS OF HARVEST AND TILLAGE OPERATIONS ON SOIL STRUCTURE

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ABSTRACT

The effects of tillage and harvest operations on soil structure and crop establishment were examined in a field experiment conducted from 1989 to 1993. Two crop rotations were combined with different decision rules in order to create contrasted levels of soil compaction risk. Soil water content was measured before each operation. Soil bulk density of wheel-tracked and non track areas was measured after each operation. Morphological aspect of the ploughed layer was observed after each crop sowing. Massive zones with no visible macropores were delimited.

Soil compaction occurred mainly with high ground pressure (more than 200 kPa), either during harvesting or crop sowing in a wide range of soil moisture. In contrast, during seed bed preparation with low ground pressure, soil compaction was low except in very wet conditions.

Soil profiles analysis was used to estimate changes with time of soil structure for each rotation. Soil compaction was very different over the four years of the experiment depending on crop rotation and the decision rules used for each crop.

INTRODUCTION

The structure of cultivated soil undergoes frequent changes due to tillage and harvest operations. Both loosening and compaction effects are involved. Compaction due to wheel tracks, that are randomly distributed or regular, and the subsequent tillage operations affect soil structure and introduce spatial variability in such processes as water, gas and heat transport, as well as root growth and establishment, in the tilled layers. Soil conditions at the time of operating in the fields are partly responsible for the degree of structure changes and their subsequent effects on the crop .

Soil conditions at harvest and tillage operations may vary due to previous soil management techniques and climate ,and rules of decision making adopted by farmers which have to overcome a number of simultaneous constraints such as crop biological requirements, climatic conditions, and work planning.

A four year field experiment was carried out to study the effects of harvest and tillage operations on the soil structure in northern France and to assess how far seedbed quality was influenced by the soil conditions at the time of previous operations. This report describes the effects of harvest and tillage operations on the soil structure at the time of crop establishment.

MATERIALS AND METHODS

Site and treatments

The experimental field at Peronne (80) was on silt loam with 18% clay (water content at field capacity : 24 %). Two crop rotations were combined with different rules of decision making:

- rotation I : pea / winter wheat / rape / winter wheat
- rotation II : sugar beet / winter wheat / maize / winter wheat

Rotation I was managed to produce as little traffic as possible in wet conditions. Rotation II was managed according to 2 rules of decision :

- rotation IIa was managed to avoid structural damage as much as possible by operating under controlled soil moisture conditions.
- rotation IIb was managed to maximise sugar beet and maize production without taking into account further structural damages. The priority was to increase the light interception period by early sowing and late harvesting. Soil preparation for early sowing in spring, as well as maize harvesting and sugar beet uprooting in late autumn were often done in rather wet conditions, that maximised soil compaction risks.

Each crop appeared every year for the 3 rotations, giving 12 treatments with 2 replicates. The plot area was 0.40 ha . It was therefore possible to reproduce the traffic pattern found on commercial farms. Mouldboard ploughing was done every year. A CASE (100 HP) tractor with low inflation pressure tyres (80 kPa) was used for seedbed preparation. Seed beds for maize and sugar beet were prepared with a combine harrow. Seed beds for the other crops (pea, wheat, rape) were prepared with a reciprocating harrow. Tyres inflation pressure of tractors used for sowing maize and sugar beet was 200 kPa. More 10 t harvester machines were used, with tyres inflation pressure of 200-300 kPa

Soil measurements

The locations of wheel tracks on the plot were recorded after each operation. Soil water content was measured before each tillage and harvest operation in each plot. Dry bulk density was measured after each operation on tracked and non tracked zones with a gamma-ray transmission probe (3 or 4 replicates per plot). Void ratio was calculated with a division into textural and structural pore space. Textural pore space was due mainly to packing of the mineral particles and structural pore space resulted from arrangement of structural elements(aggregates, crumbs,) created by tillage and/or natural cracking (1). The structural void ratio was a convenient way of expressing compressible pore space and avoided complications due to swelling and shrinkage.

The structure of the ploughed layer was assessed for each crop by the method of Manichon (2) by mapping typical macroscopic structural features on a vertical area of a 3 m wide soil profile on each plot. The profile was located in the plot according to wheel tracks. The zones with a massive structure and no visible macropores (Δ zones) were visually delimited on the soil profiles. These zones are very important for further root growth (3) and seed bed loosening (4). Photographs were taken and digitised to allow image analysis. The total area of Δ zones and the diameter of each zone was then calculated. Soil profile was divided into zones identified by the presence and origin of the tractor wheel tracks (fig. 1). Soil compaction was studied in the part of the ploughed layer where no secondary tillage occurred (PL0). The effects of tracks on soil compaction was expressed as the % (m^2/m^2) of Δ zones in the surface right underneath wheel tracks and belonging to PL0. The ratio between the Δ zones and the area of the whole layer PL0 was calculated to evaluate the change with time of soil structure during the different rotations.

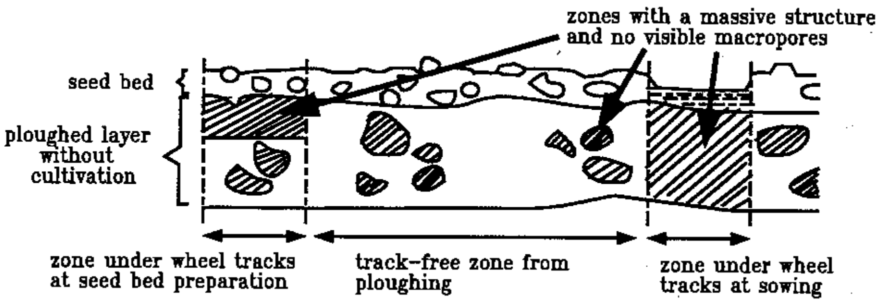

Figure 1: Simplified chart of a soil profile

RESULTS AND DISCUSSION

Soil water profile

Water content was rather high in spring and variability was due to drying (fig. 2a). At harvesting and uprooting which may occur from summer to late autumn, variability was due to rewetting (fig. 2a).

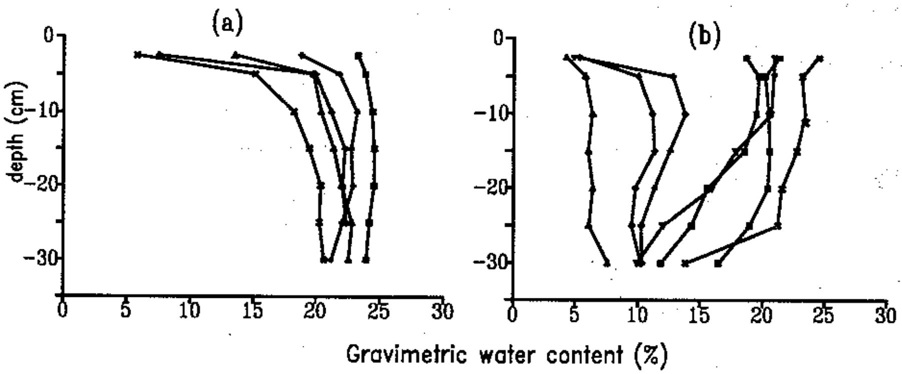

Figure 2 : Soil water content measured in 1991 in spring for seed bed preparation (2a), in summer and autumn for harvest (2b)

Effect of harvest and tillage operations on soil compaction

Structural void ratio after wheel tracks was calculated with respect to water content for different tillage and harvest operations. Soil compaction was first estimated by the structural void ratio at 10 cm depth, which was the most compacted layer. Sugar beet and maize were sown with traditional tyres (200 kPa) and water content had no effect on compaction intensity (fig. 3a). Seed bed preparation in spring was performed with low ground pressure tyres (80 kPa) in relatively wet conditions. In this case, soil compaction intensity depended on moisture content (fig. 3a) : the lower the soil water content, the lower the compaction intensity. In such conditions, low inflation pressure tyres allowed to reduce soil compaction when water content was slightly reduced. At crop harvesting, there was a relationship between soil water content and compaction intensity (fig. 3b) despite high pressure probably because of the variability of soil water content.

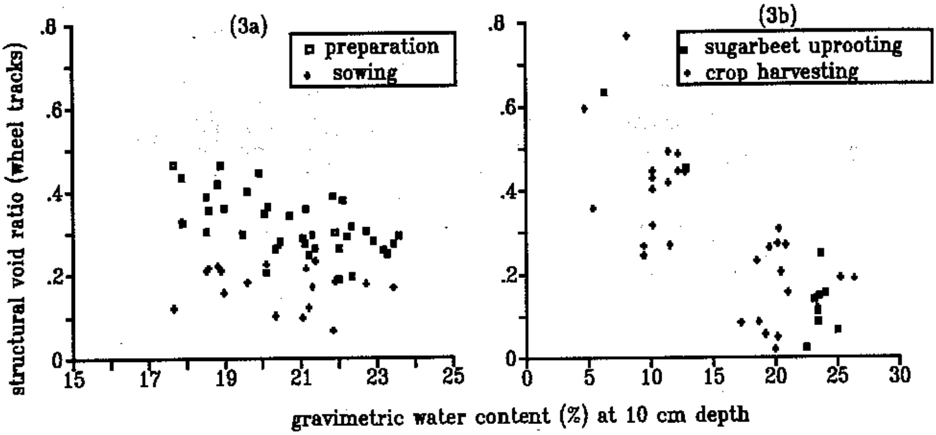

Figure 3 : Structural void ratio (at 10 cm) under wheel tracks versus soil water content (at 10 cm) at the time of track-making for seed bed preparation and crop sowing in spring (3a), or crop harvesting (3b).

The effect of initial structure, assessed by comparing tracked and non tracked zones, was only well pronounced in the case of high inflation pressure and dry soil conditions (soil water content less than 17%) at harvesting time (fig. 4). The structural void ratio under tracks was similar whatever the structural void ratio before wheeling in spring.

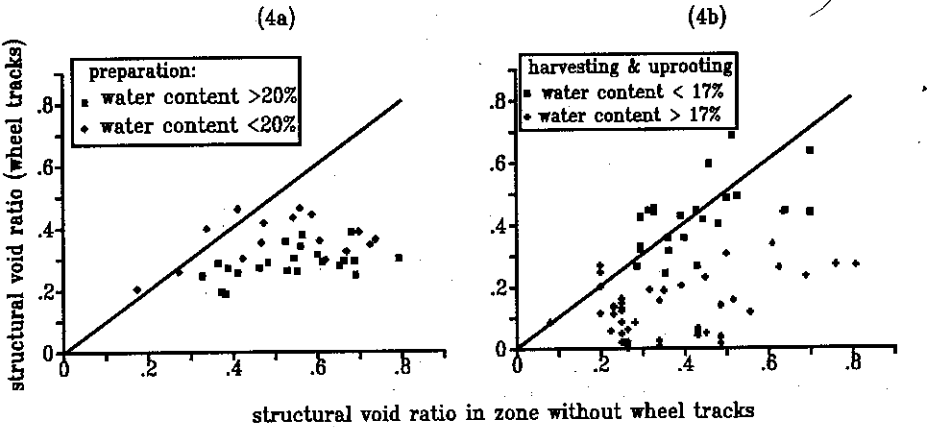

Figure 4 : Structural void ratio (at 10 cm) in the tracked zones versus structural void ratio (at 10 cm) in the track-free zones for seed bed preparation in spring (4a) and for harvesting (4b).

The other method used to study soil compaction after tracking was to assess the proportion of Δ zones in the zones of the ploughed layer affected by wheel tracks (PL0). This method took into account the morphological aspect of soil structure. During spring seed bed preparation (low inflation pressure), Δ zones with massive structure and no visible macropores occurred only in very wet conditions (soil water content greater than 22%) (fig. 5a). During maize or sugar beet sowing (high inflation pressure), Δ zones occurred over the whole range of moisture contents (fig. 5b). Results obtained by the two methods were in good agreement.

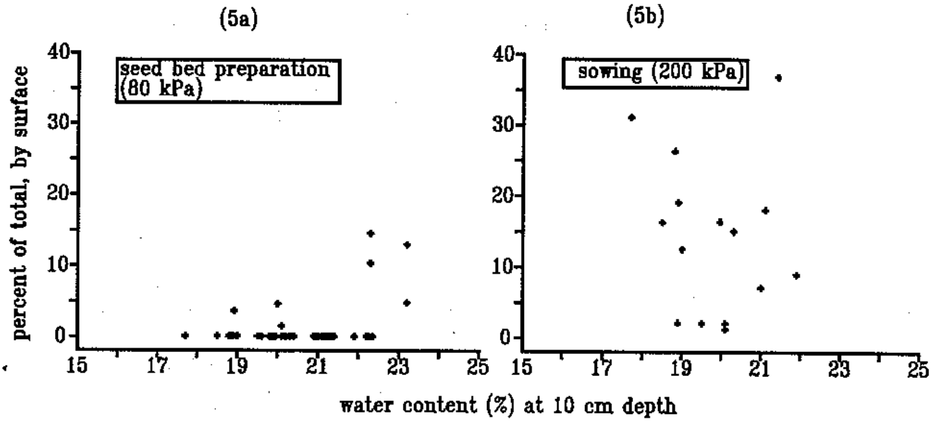

Figure 5 : Effect of soil water content (at 10 cm) at the time of track production on the ratio between area of Δ zones under wheel tracks and area of the ploughed layer affected by wheel tracks at spring seed bed preparation (5a) or at maize and sugar beet sowing (5b)

Change in soil structure with time

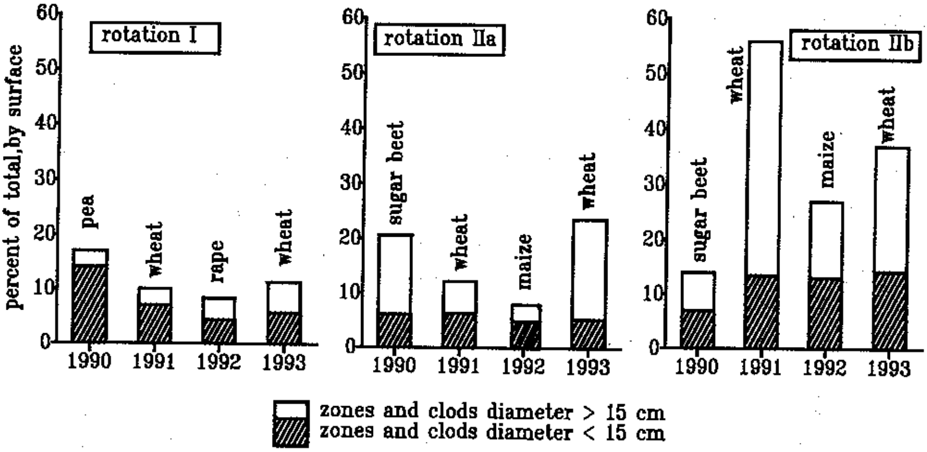

Figure 6: Change in the ratio between area of Δ zones and area of the whole ploughed layer with time for 3 crop sequences and different crops

Soil compaction, estimated by the proportion of Δ zones in the whole soil profile, varied greatly according to the rotation (fig. 6). Clods having a diameter less than 15 cm reflected the residual and cumulative effect of previous soil compaction. Clods having a diameter greater than 15 cm reflected recent soil compaction. Rotation IIb was the most harmful with respect both to recent compaction and cumulative effects of soil compaction. The proportion of Δ zones also varied greatly during a rotation. In rotation IIb, it was greater during the wheat crop, especially after sugar beet : compaction induced by uprooting in wet conditions affected 80% of the plot area. The proportion of Δ zones decreased during the maize crop because wheat harvesting was performed in dry conditions, mouldboard ploughing induced an overall loosening of the tilled layer, which has been subjected to weathering, and seed bed preparation for maize did not induce serious compaction. However, these conditions did not induce a sufficient decrease of Δ zones such as to obtain a soil structure similar than in rotation I or IIa.

CONCLUSION

Soil compaction occurred mainly during harvesting in wet conditions because of the high ground pressure applied to the soil surface. In contrast, soil compaction was low during seed bed preparation in spring, with low ground pressure. These results are consistent with many studies (1, 5 and 6). Soil compaction was very different at the end of the four-year experiment depending on the crop rotation and the rules of decisions making. The first results of this experiment are promising. The methodology developed to assess soil structure will allow to analyse better what strategies of risk assessment and rules of decisions making should be developed to avoid the cumulative effects of soil compaction in the tilled layer.

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SOIL COMPACTION CONTROL, SLURRY DISPOSAL AND NITROUS OXIDE FLUXES ON GRASSLAND FOR SILAGE

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ABSTRACT

In a field experiment in Scotland, perennial ryegrass was harvested for silage three times each year on soil at various stages of compaction after traffic. Nitrogen fertiliser was supplemented by livestock slurry at two application rates. Grass growth, yield and nitrogen offtake, and rate of infiltration of slurry, benefitted significantly from control or avoidance of soil compaction. The amount of nitrous oxide emitted from the soil after N applications was reduced markedly by limiting the severity of compaction damage.

INTRODUCTION

Recommendations to reduce both the expenditure on mineral fertiliser and the environmental impact of nitrogenous gases have prompted renewed interest in specification of the crop nutritional value of livestock wastes. In many parts of NW Europe, perennial grassland is the most common venue for disposal of livestock slurry; typically, the grassland in these areas is managed for conservation as silage. Previous research on grassland for silage has shown that conventional wheel traffic compacts the soil to such an extent that conditions are frequently below optimum for grass growth(1,2). Mitigation of wheel-induced compaction leads to relatively heavier yields, associated with markedly improved uptake of applied fertiliser-nitrogen, and reduced denitrification and emissions of nitrous oxide(3,4,5,). We report here on the first two years of a study of the interaction between soil compaction and slurry disposal on perennial grassland, with particular reference to effects on yield and nitrogen utilisation and losses.

MATERIALS AND METHODS

Site, soil and treatments

The experiment is located 10 km south of Edinburgh, Scotland, at an altitude of 200 m on an imperfectly drained clay loam soil. The site is gently sloping with a south-east aspect. The land is typical of that used in Scotland for silage production and has been classified as having potential for average to high yields of grass; among the recognised limitations of such land are wetness, restricted rooting depth and structural weakness.

The plots were 2.4 m by 28 m and, by use of appropriate wide-track tractors and machines, were sown, fertilised, mown and harvested without the intrusion of wheel traffic. Compaction treatments were prepared by successive adjacent passes by an appropriate tractor along the length of plots. In the first year (1992), *zero* compaction (no traffic) was compared with *typical* compaction (traffic by 5 t tractor); in the following year, a third treatment, *controlled* compaction (traffic by 4 t tractor with low ground pressure tyres) was introduced. Slurry was applied from a 2.8 -m track tanker with a pto-driven centrifugal pump which delivered the material to a 2.4 m curtained dribble bar. Slurry was applied in the spring, and after first and second harvests, at three rates, nominally 0, 1 and 2: rate 0 was nil, and rate 2 was double that of rate 1. The amounts of nitrogen applied for each harvest in slurry (ammoniacal-N) and mineral fertiliser (ammonium nitrate) are shown in Table 1. All plots received basal applications of phosphate and potassium fertiliser.

Table 1. Amounts of nitrogen applied on each of three occasions in each year.

Year/application number		Fertiliser-N, kg ha^{-1}	Slurry-derived NH_4^+-N, kg ha^{-1}	
	Slurry rate:	0	1	2
1992 / 1		60	29	59
/ 2		50	25	51
/ 3		0	31	56
1993 / 1		60	28	56
/ 2		50	22	44
/ 3		0	38	76

Soil, crop and nitrogen measurements

Soil. Water content, dry bulk density and air-filled porosity were calculated for the 0-75-mm depth from 36-mm diameter core samples. Cores were collected immediately before each slurry application. Hydraulic conductivity was measured in the field using tension infiltrometers positioned on the soil surface.

Crop. Herbage mass accumulation and grass height were monitored weekly during the growing season using a drop-disc meter. Dry matter yields, equivalent to three harvests for silage, were obtained by collecting four 1 x 0.1 m cuts per plot using battery-operated, hand-held clippers.

Nitrogen. At each harvest, in addition to the four yield samples, one sample per plot was taken for determination of grass nitrogen content. Offtake of N in herbage was calculated as the product of N concentration and dry matter yield. Nitrous oxide fluxes were assessed on each slurry rate-2 plot by a closed-chamber (400 mm diameter x 150 mm height) technique. Gas samples were taken by syringe (5 ml) after sealing each chamber for 1 hr., and their N_2O content determined subsequently by gas chromatography. Measurements were made daily after slurry application until fluxes became negligibly small, after which sampling was weekly.

Weather and soil water deficits

The growing seasons (April-September) in 1992 and 1993 were wetter than average, especially the latter. Potential soil water deficit, which on average peaks at around 110 mm in July-August, did not exceed 80 and 40 mm in 1992 and 1993, respectively (Fig. 1). In the first year, the soil remained at or above field capacity until mid-May and returned to that condition in mid-August; in the second year, the only significant soil drying was shown by low peak deficits in July, August and September.

RESULTS AND DISCUSSION

Soil properties

Soil bulk density increased from *zero* to *controlled* to *typical* compaction, and the volume of air-filled pore space decreased in the same order (Table 2). Because of relatively large water contents, air-filled pore volumes were smallest on the occasions of the first slurry application in the spring of both years, and of the second application in summer 1993. Effective hydraulic conductivity at the soil surface, and hence the rate of infiltration of slurry, was reduced significantly by *typical* compaction relative to the *zero* treatments: in spring 1992, by a factor of 200, and in spring 1993, by a factor of 10.

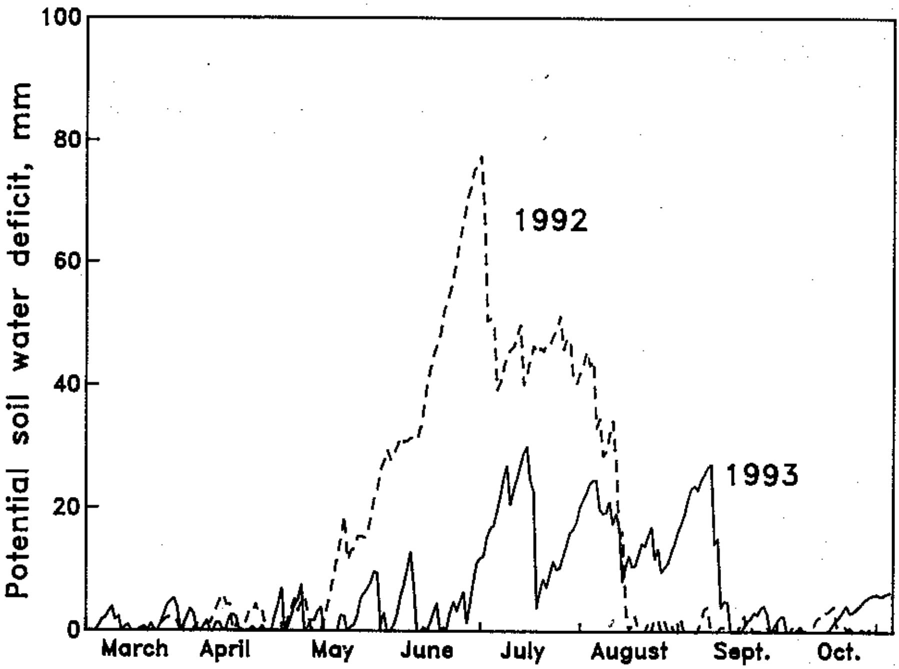

Fig. 1. Potential soil water deficits during March to October in 1992 and 1993.

Table 2. Soil properties in the 0-75-mm layer on the occasions of the three slurry application in 1992 and 1993.

Application/ *Compaction treatment*	Dry bulk density, Mg m^{-3}		Water content, v/v, %		Air-filled porosity, v/v, %	
	1992	1993	1992	1993	1992	1993
First						
Zero	1.13	1.17	41.4	43.6	14.6	10.7
Controlled	-	1.21	-	45.0	-	9.6
Typical	1.32	1.30	47.8	44.9	1.8	4.2
s.e.d.	0.017	0.015	0.82	1.15	0.95	1.03
Second						
Zero	1.10	1.16	15.4	45.9	42.5	9.7
*Controlled**	-	1.20	-	37.1	-	16.9
Typical	1.39	1.34	19.2	45.5	27.6	3.5
s.e.d.	0.035	0.042	0.68	1.38	1.98	2.78
Third						
Zero	1.13	1.17	34.5	26.1	22.2	29.2
Controlled	-	1.18	-	27.1	-	27.9
Typical	1.34	1.25	39.2	25.2	9.4	27.0
s.e.d.	0.028	0.060	0.41	1.23	1.43	3.42

Note: *Second slurry application to *controlled* treatment made the day before the application to the other treatments.

Grass growth and yield, and nitrogen offtake

As a result of larger dry matter accumulations, especially in the primary growth periods, total harvest dry matter yields were heavier in the *zero* and *controlled* compaction treatments than in the *typical* treatment in both years at each slurry rate (Table 3). In the first year, the annual yield advantage from compaction control was mainly a result of a gain at first harvest. In the second year, greater yield at both first and second harvests from the *zero* and *controlled* treatments contributed significantly to the larger annual yields relative to the *typical* compaction treatment.

Table 3. Dry matter yield from three slurry rates at three harvests in 1992 and 1993.

Compaction treatment		1992			1993		
	Slurry rate:	0	1	2	0	1	2
First harvest							
Zero		4.13	4.80	5.66	4.22	4.95	5.32
Controlled		-	-	-	-	4.75	5.21
Typical		3.51	4.14	4.35	1.96	3.10	3.68
s.e.d.			0.125			0.227	
Second harvest							
Zero		2.75	3.43	3.70	3.76	4.27	4.82
Controlled		-	-	-	-	4.01	4.46
Typical		2.81	3.29	3.88	2.54	3.54	3.94
s.e.d.			0.232			0.217	
Third harvest							
Zero		0.93	1.74	2.45	0.99	1.43	2.57
Controlled		-	-	-	-	1.43	2.25
Typical		0.73	1.51	2.26	0.80	1.10	2.46
s.e.d.			0.093			0.152	
Total							
Zero		7.81	9.97	11.81	8.97	10.64	12.71
Controlled		-	-	-	-	10.18	11.92
Typical		7.05	8.93	10.49	5.30	7.74	10.08
s.e.d.			0.219			0.419	

A consistent trend of smaller concentrations of nitrogen in the grass at harvest in the *typical* compaction treatment, together with the afore-mentioned dry matter deficit, resulted in lower recoveries of applied nitrogen than were gained from the *zero* and *controlled* treatments. Annual offtakes (kg N ha^{-1}) were as follows: *zero* = 210 and *typical* = 173, in 1992, and *zero = 183, controlled* = 174 and *typical* = 120, in 1993. Compared to that from the *zero* and *controlled* treatments, offtake of N from the *typical* treatment was especially small at the first harvest in the second season: for example, at slurry rate-2, 41 kg ha^{-1} from the latter treatment and an average of 83 kg ha^{-1} from the former.

Emissions of nitrous oxide were generally largest from the more compact soil of the *typical* treatment following applications of slurry and fertiliser (Fig. 2), or slurry alone (Fig. 3). Peak N_2O emissions tended to occur within 10 days of application of the slurry, and on some occasions were 2 to 3 times larger from the soil of the *typical* treatment than from the others.

Interactions

Dry matter yields tended to decreased with increasing compaction, with the exception of the second harvest in 1992 when there were no significant differences. The first regrowth period leading to that second harvest was the only period in which the slurry and fertiliser were both applied and utilised in conditions characterised by low rainfall and dry soil (Fig. 1). In each of the other crop growth periods, the soil was relatively wet (close to field capacity) when growth commenced, or became so soon afterwards.

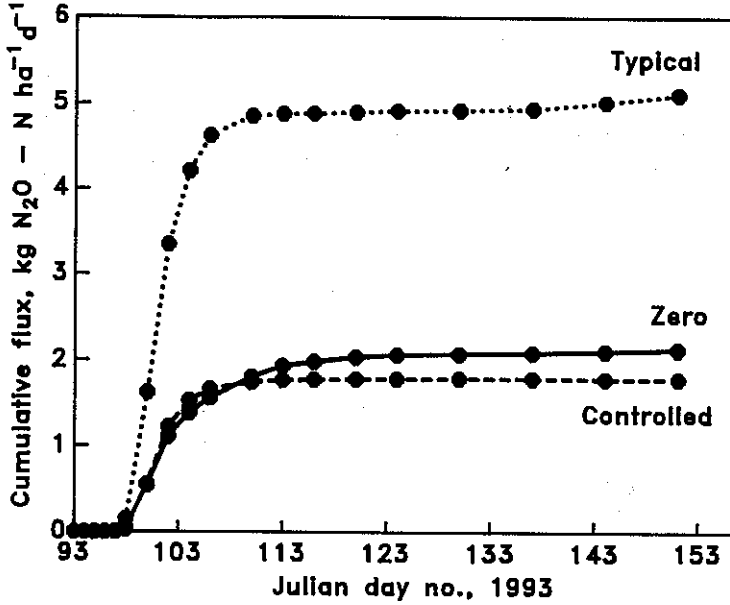

Fig. 2. Cumulative flux of N_2O-nitrogen in spring of 1993. Slurry was applied on day 95, and fertiliser applied on day 97.

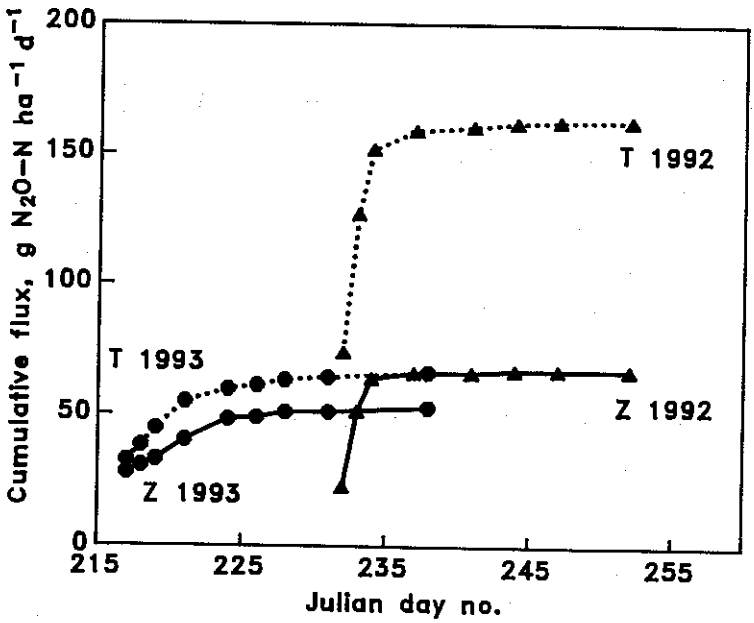

Fig. 3. Cumulative flux of N_2O-nitrogen from the *zero* (Z) and *typical* (T) compaction treatments after the third slurry application in each year (applied on day 231 in 1992, and on day 216 in 1993).

Trends in N-uptake by the grass, and N-offtake at harvests, were similar to the yield patterns and likely also to have been influenced significantly by soil wetness and associated volumes of air-filled pore space.

Emission of N_2O mostly occurred soon after nitrogen application, and trends between treatments and occasions were related, at least in part, to the amount of air-filled soil porespace at the time of N application. For example, at the time of the third application, in the *typical* treatment, the soil was much wetter (Table 2) and the N_2O flux almost three times larger (Fig. 3) in 1992 than in 1993.

Losses of N as gaseous ammonia were not measured, but given the markedly lower conductivity of the soil surface layer in the *typical* compaction treatment, it is probable that ammonia volatilisation was largest in that treatment[6].

CONCLUSIONS

1. The more porous soil present when compaction was controlled or eliminated was more conducive to rapid infiltration of slurry, growth of grass, and utilisation of nitrogen, than soil that had received a typical level of compaction. The effects of compaction were most pronounced in wet conditions, in either spring or summer.

2. Environmentally harmful emissions of nitrous oxide from the soil were reduced when an adequate proportion of air-filled pores was sustained by either low water content or a low degree of compaction.

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PHYSICAL, CHEMICAL AND BIOLOGICAL DEGRADATION OF AGRICULTURALLY UTILIZED SOIL

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ABSTRACT

The effects of long-term and various agricultural soil utilization on physical, chemical and biological properties were presented. In objects with high mineral fertilization and herbicide application rates the intensive soil degradation occurred. It was resulted in lower water stability of soil structure, organic matter content, enzymatic activity and number of microorganisms and greater soil acidity. The results indicated the existence of physical, chemical and biological degradation of soil, especially in herbicide strips of orchard and black currant plantation.

INTRODUCTION

Recent studies provide more and more frequently evidence that agricultural soil utilization leads to changes in soil morphology combined with changes in physical, chemical and biological properties of soil (1,2,3). In the agriculturally utilized soils the course of the changes is closely related to the type of soil use, crop rotation, fertilization, degree of the mechanization of agronomic practices and application of the herbicides (4,5,6).

The results we have obtained hitherto indicate, that intensive agriculture may lead to the soil degradation. It is shown by increase in soil compactness and deterioration of aggregate soil structure (7), lower organic matter content (8), enhanced acidification (9) and lower biological activity, especially under the herbicide strips of orchard and black-currant plantation (10).

The studies aiming at the evaluation the effect of intensive agriculture on soil biological activity are of particular importance since the response of microorganisms to agrotechnical measures is very similar to that of cultivated plants. Numerous results give evidence, that the application of high mineral fertilization rates and herbicides hamper the growth of some groups of bacteria and the rate of biological transformations in the soil (6,10,11,12,13).

Interdisciplinary studies were undertaken to evaluate more precisely the danger of soil degradation of agriculturally used soils and to give the recommendations for their reclamation.

MATERIALS AND METHODS

The detailed studies were conducted on 6 objects which were selected on the area with soils derived from silts. The history of long-term management of the soils is known. The particular objects fundamentally differed in respect to tillage methods and intensity of the application of agrotechnical measures.

Soil in field culture-arable land of differentiated crop rotation. Mineral fertilization and plant protection measures were adjusted to the needs of individual plants.

Object I - field with six-field crop rotation system has been used for 30 years. The soil samples for the analysis were taken in the year of wheat cultivation;

Object II - productive field of a large-scale farm cultivated for tens of years. The soil samples were taken in the year of alfalfa cultivation;

Soil under apple tree orchard; mineral fertilized with 525 kg NPK ha^{-1} since 12 years. The following herbicides were used: Gesatop 3-4 kg ha^{-1}, Gramoxone or Reglone and Roundup 5-6 kg ha^{-1}.

Object III- herbicide strips;

Object IV - grass strips;

Soil under black currant plantation.

Object V - ten-years old plantation of black currant, var. Rodknap. Before planting a special ploughing had been made to the depth of 40 cm. Mineral fertrilizers were applied as follows: N 65 kg ha^{-1}; K 75 kg ha^{-1} and Florovit into leaves. For the weed control the herbicides Goa I, Duaz, Fuzylade and Kerp were used;

Object VI - field after black currant, chopped sprouts were ploughed in spring 1992. In 1993 spring rape was sown for soil reclamation.

From all the objects studied the soil samples were taken from the humus horizon, layer 2-17 cm. For the biological activity determinations soil samples were taken 3 times (spring, summer and autumn) in two years: 1992 and 1993. The following determinations were made:
- bulk density and total and differential porosities in undisturbed soil cores of 100 cm^3;
- soil texture with the aerometric method;
- C-total with the Turin's method;
- pH electrometrically;
- water stability of soil aggregates with the Baksheyev's method;
- sorption capacity and base saturation with the Kappen's method;
- dehydrogenase activity with the Thalmann's method;
- so-called neutral phosphatase activity (pH=6.5) with the Tabatabai et al. method;
- urease activity with the modified Zantua's method;
- macrotrophic and oligotrophic bacteria frequency number according the method of Hattori;

RESULTS AND DISCUSSION

The physical properties of soil

The soil investigated was characterized by relatively low compactness. However, the various types of the soil utilization were reflected in results of bulk density, total porosity and differential porosity (Table 1). The most compacted soil occurred in the interrows of black currant plantation. This can be related

Table 1 Some physical properties of the soil tested.

Objects	Fraction <0.02 mm %	Bulk density Mg m^{-3}	Total porosity %	Content of pores (%, v/v) >20μm	20-0.2μm	<0.2μm
I*	31	1.39	47.2	8.9	30.5	7.8
II	33	1.46	44.0	8.2	27.5	8.2
III	33	1.39	46.8	14.6	24.6	7.6
IV	34	1.45	44.1	9.4	26.6	8.1
V	42	1.57	39.8	2.5	27.6	9.7
VI	49	1.24	52.2	18.2	26.6	7.4

*I -field with six-field crop rotation system;
II -field with typical intensive tillage;
III -herbicide strip apple tree orchard;
IV -grass strip apple tree orchard;
V -black currant plantation;
VI -after black currant plantation field.

to the lack of plant cover, regularly destroyed by the herbicides, and to the compactive effect of full mechanization of field practices. Gley spots, which were observed in the interrows, indicate insufficient soil aeration. This was confirmed by extremely low contribution of macropores (2.5 %, v/v). However, in the field after black currant, high loosening and considerable improvement of soil aeration was noted. Physical state of the soil in the remaining objects was not meaningly different.

Table 2 Content of water resistant aggregates of the soil tested.

Objects	Water resistant aggregates %,w/w >7 mm	7-5 mm	5-3 mm	3-1 mm	1-0.5 mm	<0.5 mm
I*	4.4	3.5	5.2	9.4	12.4	65.1
II	1.5	1.0	5.2	7.2	15.1	70.0
III	1.0	1.2	1.5	3.2	6.7	86.4
IV	3.7	5.1	7.6	10.9	17.6	55.1
V	1.4	1.7	1.2	9.3	14.9	71.5
VI	2.3	2.3	4.1	7.9	14.0	69.4

*Explanations as in Table 1.

Analyze of the results of water stability of soil structure (Table 2) implies interesting remarks. It indicates, that intensive application of the herbicides and high mineral fertilization cause a pronounced decline of agriculturally beneficial aggregates, especially the fraction of 3-5 mm. This can be indicative of the soil degradation although the soil did not show high level of compactness.

The chemical properties of soil

Taking into consideration conventionally tilled soil as a reference, the most pronounced symptoms of soil chemical degradation were found in the herbicide strips of the apple orchard (Table 3). It was shown by lower organic matter content, higher acidification and tremendous drop in the saturation of sorptive capacity with the base cations. This response was closely linked with high mineralization rates and insufficient liming.

Table 3 Basic chemical properties of the soil tested in two years.

Objects	C-total mg/100g		pH in 1M KCl		Sorption capacity cmol(+)kg^{-1}		Base saturation %	
	1992	1993	1992	1993	1992	1993	1992	1993
I*	980	940	4.8	4.3	7.66	8.80	52.80	67.61
II	836	928	5.4	5.6	9.34	11.50	74.90	82.78
III	796	828	4.1	3.7	7.37	10.03	38.05	30.30
IV	936	1006	5.5	4.2	8.68	9.46	69.10	61.73
V	840	780	6.1	5.3	8.78	8.54	82.20	81.85
VI	796	700	6.8	6.7	10.95	11.47	88.90	93.98

*Explanations as in Table 1.

Enzymatic activity

The lowest activity of all the enzymes studied was found in the soil of the herbicide strips in the orchard. In the strips,

Table 4 Activity of some enzymes (mean values in two years: 1992 and 1993).

Objects	Dehydrogenase mcg TPF/1g soil/24h		Phosphatase mcg PO_4/1g soil/1h		Urease mcg N-NH_4/1g soil/24h	
	1992	1993	1992	1993	1992	1993
I*	4.62	5.45	138.34	113.77	486.03	447.22
II	4.38	6.37	106.32	118.58	435.53	494.88
III	1.42	1.58	52.12	40.95	164.46	148.50
IV	4.83	6.38	135.77	120.29	293.09	347.84
V	3.38	4.75	74.92	63.49	396.31	282.98
VI	5.44	2.48	86.91	83.62	610.60	411.78

*Explanations as in Table 1.

activities of dehydrogenase, neutral phosphatase and urease weredecreased more than twice (Table 4). Also one should state, that the exceptionally low enzymatic activity of soil corresponded with low content of total carbon and high acidification. Similar relations were observed in the herbicide strips of the black currant plantation but they were not so clear as those in the orchard. In the grass strips of the apple orchard the enzymatic activity was relatively higher and not much different from the enzymatic activity of the conventionally tilled soil.

Number of bacteria

As with enzymatic activity, the number of macrotrophic and oligotrophic bacteria in the soil was considerably reduced in the herbicide strips of the orchard and less in the strips of the black currant plantation (Table 5).

Table 5 Numbers of bacteria (mean values in two years: 1992 and 1993).

Objects	Macrotrophic bacteria million/1g soil		Oligotrophic bacteria million/1g soil	
	1992	1993	1992	1993
I*	30.90	18.08	10.57	15.17
II	20.08	18.33	6.89	18.83
III	1.98	2.45	1.48	0.75
IV	17.66	15.77	7.06	13.02
V	9.76	12.84	3.19	13.13
VI	20.93	16.29	8.86	8.92

*Explanations as in Table 1.

CONCLUSION

The studies indicated that high mineral fertilization combined with application of herbicides for weed control in the orchard and black currant plantation leads to considerable soil degradation. The degradation is shown by lower organic matter content, greater acidification and lower base saturation of the sorptive capacity. This resulted in lower number of bacteria and more than double drop in the enzymatic activity. As a cosequence water stability of soil structure decreased. It was shown that the properties studied, especially enzymatic activity and water stability of soil structure can be valuable indicators for the evaluation of the degree of soil degradation.

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ASSESSMENT OF THE SOIL PHYSICAL PROPERTIES CREATED BY THREE TILLAGE SYSTEMS FOR RAINFED CEREAL CROPS IN CENTRAL SPAIN.

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ABSTRACT

During the periods 1989-90 and 1990-91, studies were performed to determine the structural porosity and available water accumulated in a clay loam. Three treatments were compared: conventional tillage (CT), minimum tillage (MT) and direct drilling (DD). A distinction was made between two zones for each of the above treatments: non-compacted (NC) and compacted (C) by mechanical equipment.
Structural porosity is reduced to a minimum in winter, as a result of swelling of the soil due to its high moisture content. As moisture is lost structural porosity increases owing to processes of shrinkage, which in summer give rise to the appearance of cracks in the soil.
As regards the effective water content accumulated in the soil profile, this is higher during sowing in the case of CT, although the opposite occurs during the critical stages of crop growth (spring barley 1989-90 and winter barley 1990-91).
In autumn, the effects of the treatments and sub-treatments tend to disappear before tilling is performed. Good drainage and natural aeration are two aspects which allow conservation tillage systems to be used for the soil on which these experiments were carried out.

INTRODUCTION

One possible way in which to study the evolution of the structure of soils subjected to different mechanical and climatic actions is based on long-term assessment of porosity. This variable is a conditioning factor as regards movements of water and the amount of oxygen available for root development (1), (2), (3).
Tillage systems have an important influence on the state of the soil, and consequently on the aforementioned variable. Tilled soils initially show a larger volume of transmission pores than untilled soils in the zones affected by the different implements used. These differences tend to decrease with time, mainly as a result of climatic activity. This paper attempts to differentiate between textural and structural porosity. The first of these is intrinsic to the granulometric constitution of the soil, while the second is due to climatic, biological and mechanical action (4), (5), (6). Structural porosity shows more clearly the variations that occur in the physical state of the soil with time (7).
Along with structural porosity, the water available to the plants is another variable conditioning crop development. Conservation tillage systems maintain higher levels of such available water than do conventional methods. In those areas in which rainfall is

a limiting factor, assessment of this variable is of great interest.

MATERIALS AND METHODS

The experiments were carried out during the periods 1989-90 and 1990-91 on a clay loam soil (Alfisol, Xeralf, Haploxeralf, Vertic). This soil has good natural drainage and is very expansive due to its clay fraction being made up of montmorillonite. The average content of organic matter in the arable layer is 1%, and its pH is 7.8. The crops sown in each of the different periods were: spring barley (1989-90) and winter barley (1990-91). The site at which the experiments were carried out was the "El Encín" Experimental Station, which belongs to the Agricultural Research Service of the Autonomous Community of Madrid, located 38 kilometres North-East of Madrid.

Soil tillage treatments and soil sampling

Three main treatments were compared: CT (Conventional Tillage to 30 cm depth), MT (Minimum Tillage to 15 cm depth) and DD (Direct Drilling). For each type of treatment, a distinction was made between two different zones: NC (Non-Compacted) and C (Compacted). Both zones were established depending on the proximity and overlapping of the tractor ruts for each of the mechanical operations involved in preparing and fertilizing the soil and in sowing. Samples were taken during five different periods of the year, mainly coinciding with the period of crop development.
Following identification of the non-compacted and compacted zones for each treatment, samples were taken to determine the gravimetric soil moisture (% W/W) and the bulk density of the soil. For this purpose a transection measuring 2 metres in length was selected, running perpendicular to the direction of the sowing lines and covering both zones. The samples were taken to a depth of 40 cm at intervals of 5 cm.
The swelling-shrinkage line (fig.1) had been determined previously in the laboratory using aggregates of 2-3 mm and in accordance with the method described by Monnier et al. (4), for calculation of textural porosity. Structural porosity was obtained on the basis of the difference between the total and textural porosities.
The moisture retention curve was also plotted in order to determine the field capacity, (pF 2.7 = 16.11%) and wilting point (pF 4.2 = 8.13%), in order to determine the available water accumulated in the soil profile (mm) to a depth of 40 cm.

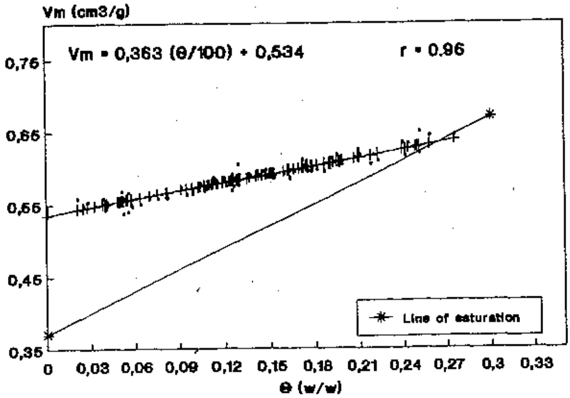

Fig.1: Line of swelling - shrinkage.

RESULTS AND DISCUSSION

Structural porosity

The evolution with time of structural porosity (SP) is shown in figures 2 and 3, this corresponding to the periods 1989-90 and 1990-91. Statistical analysis was carried out in all cases, but is not reflected in this paper for reasons of space limitation.
The treatments and sub-treatments followed similar trends with time during both periods. At the time of sowing the CT and MT treatments showed the highest values at the surface, these decreasing with depth and equalling out in the non-worked area of the soil. The DD treatment shows practically constant values with depth. The maximum differences with respect to other treatments reach 19% in the non-compacted zone and 18% in the compacted zone. Comparison of the two zones for one same treatment show differences of up to 12% in the tilled soil and 7% in the case of direct drilling. This is due to working of the soil and to the effects of mechanical compaction.
As from the moment of sowing, the climatological conditions are responsible for the greatest variations in structural porosity. During periods of rainfall, this variable reaches minimum values, for both treatments and sub-treatments. This is due to the expansion experienced by the soil as water recharge occurs, which tends to neutralize the effects produced by working. The volume of structural pores decreases to levels of no more than 20% (CT), 11% (MT) and 10% (DD) in the non-compacted zone. As regards the compacted zone, the average values do not exceed 10% (CT), 8% (MT) and 5% (DD); for this latter treatment there are even certain periods during which structural porosity is practically inappreciable.
The loss of soil moisture occurring between the middle of May and the end of June causes strong retraction, as a result of which cracks of different sizes appear, increasing structural porosity. In most cases, there are no significant differences between treatments in the compacted zone as the month of July sets in. In the non-compacted zone such differences have been observed only to a depth of 15 cm and between MT and DD.
At the beginning of autumn, the soil is under practically the same conditions every year, with the effects of both treatment and subtreatment being minimum or non-existent.
In view of its good drainage and natural aeration, the soil is suitable for conservation tillage, and especially for direct drilling.

Available water

Figure 4 shows the results for tbe effective water accumulated in the soil profile during the periods studied. As in the case of structural porosity, there is great similarity in tbe behaviour of treatments and sub-treatments. At the time of sowing, conventional tillage provides larger amounts of available water (> 30 mm) than do the other two treatments. This indicates that soil relcharge occurs more rapidly as a result of tillage and the depth to which it is performed.
During the winter, the content of effective water is significantly higher in the case of direct drilling than for the other two types of treatment, CT and MT, due to the higher levels of evaporation and drainage occurring in these latter cases.
When the period of moisture deficit arrives, the conservation tillage methods, MT and DD, provide significantly higher values than those corresponding to conventional tillage. In fact, the plants extend their vegetative period - this prolongation lasting longer the less the soil has been altered - although grain maturity is reached on practically the same date in all cases.

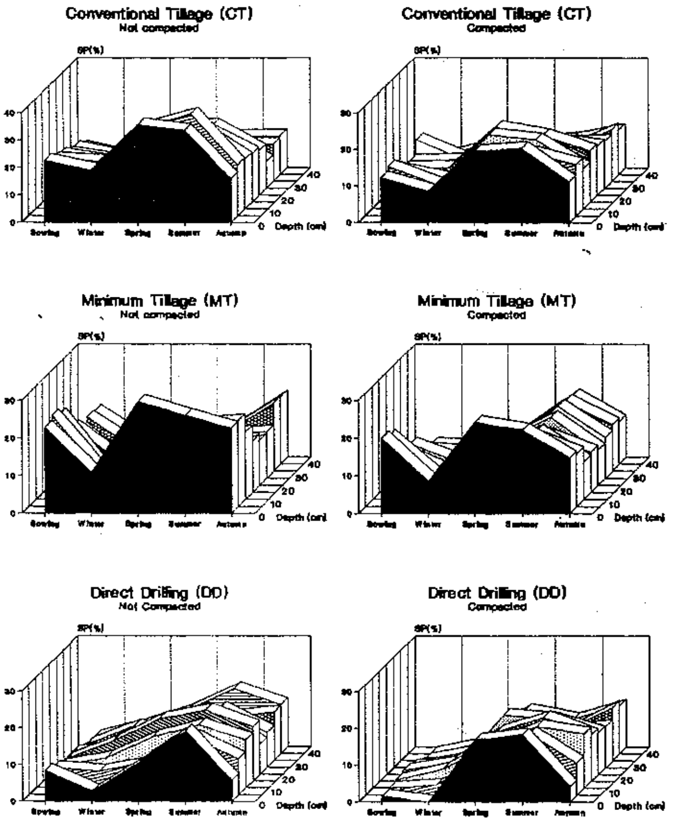

Fig.2: Structural Porosity (SP) evolution (1989/90).

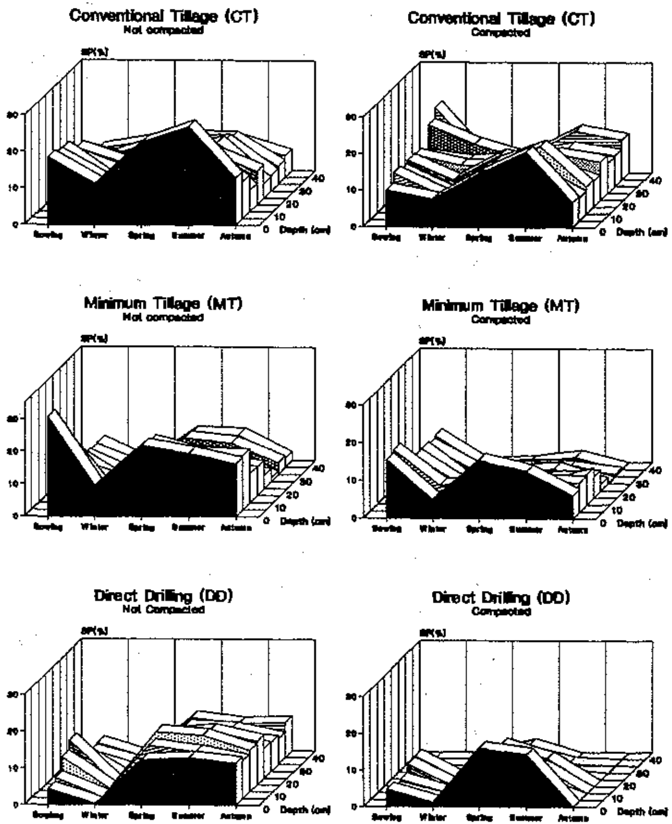

Fig.3: Structural Porosity (SP) evolution (1990/91).

In summer, the volume of effective water is zero, due to the high temperatures reached and the low amount of rainfall.
By the beginning of autumn, the effects of treatment and sub-treatment may be said to have disappeared. The statistically significant differences encountered do not make it possible to draw conclusions pointing to the predominance of one system over the others.
The differences observed in comparing the compacted and non-compacted zones corresponding to each treatment are minimum. Significant differences are obtained only at the time of sowing and in autumn, prior to tilling. No such differences were observed in any case during the period of crop growth.

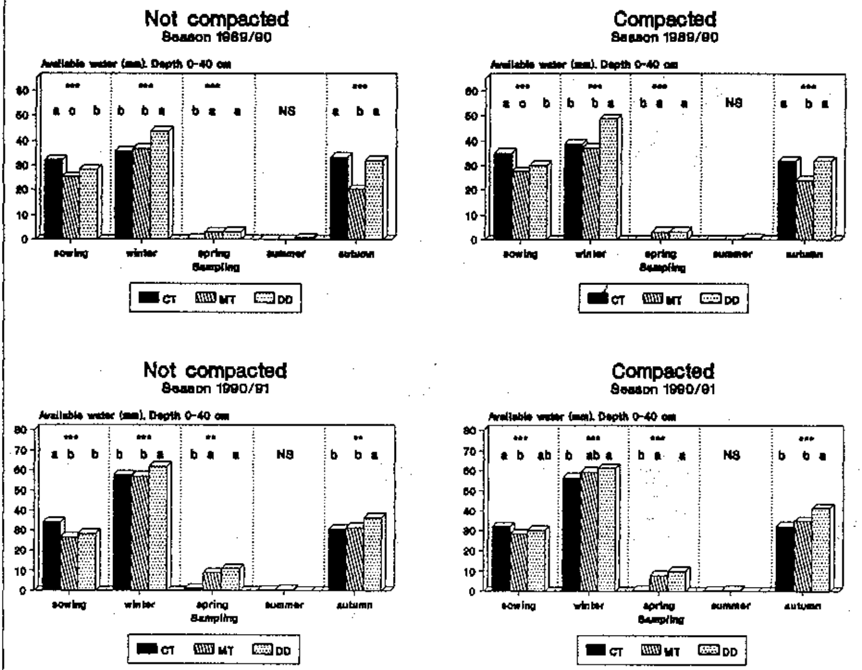

Fig.4: Available water (mm) in two seasons

*** : p ≤ 0.01
** : p ≤ 0.05
NS: not significant

CONCLUSIONS

As regards structural porosity, the effects of tillage are considerably reduced due to the soil swelling process that occurs during the period of rainfall. Minimum values are attained during the winter.

As the soil loses moisture, structural porosity increases as a result of retraction of the soil, the maximum values being reached at the end of spring and during the summer.

The volume of soil available water was higher in the case of MT and DD treatments than for CT during the period of crop growth, although the latter treatment provided higher values at the time of sowing.

The variables analyzed showed minimum differences between the compacted and non-compacted zones, the same trend being followed with time. At the beginning of autumn, the soil reaches a state in which the effects of tillage and compaction practically disappear.

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CORN PRODUCTION AND SOIL EROSION AFTER SOD ON AN ERODED LANDSCAPE AS AFFECTED BY TILLAGE

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ABSTRACT

The Conservation Reserve Program (CRP) authorized by the 1985 United States Congressional Farm Bill compensated farmers for returning highly erodible or environmentally sensitive land to permanent sod cover. This is a 10-year volunteer program with contracts beginning to expire in 1995. The question on how these lands should be managed after CRP has not been adequately addressed. This project was designed to measure how these lands will respond when brought back into crop production and soil erosion potentials of these lands after long-term sod. Plots were initiated in an established alfalfa (*Medicago sativa* L.)-smooth bromegrass (*Bromus inermis* Leyss.) sod across an eroded landscape. Initial treatments established in the alfalfa-bromegrass sod were moldboard plow, chisel plow, and no-till in the spring of 1990. In each subsequent year through 1993, another no-till treatment was established. A continuous corn (*Zea mays* L.) rotation was grown on all plots. Corn yields were measured each year and analyzed by tillage system and topsoil depth. Rainulator trials were conducted in 1993 on all treatments and on the alfalfa-bromegrass sod check. Artificial rainfall was applied at an intensity of 63.5 mm hr^{-1} for 60 min in a dry run on antecedent soil moisture and a wet run a minimum of 6 hours after the dry run. Corn yields were not significantly different among tillage systems or to topsoil depth. The grass check and all no-till treatments had no water runoff or soil erosion. The moldboard plow treatment was highly erodible. Results from this study show that no-till management will be an acceptable option for erodible lands that have been in long-term sod.

INTRODUCTION

The Conservation Reserve Program (CRP) was authorized by the 1985 United States Congressional Farm Bill. The objective of CRP was to assist landowners of highly erodible cropland in conserving and improving the soil and water resources of their farms or ranches. About 14 million hectares were enrolled in the United States by 1992, somewhat short of the goal of 18 million hectares. CRP is a voluntary 10-year program which compensates farmers for returning highly eroded or environmentally sensitive land to permanent sod cover. The 10-year CRP contracts will begin to expire in 1995. Heimlich and Kula (1) estimate that no more than 20% of CRP lands will remain in grass when the program is finished. There are three major uses for CRP lands. The first without regard to race, color, national origin, could be to leave these lands in grass for wildlife habitat; secondly, these lands could be used as

All programs and services of the U.S. Department of Agriculture are offered on a nondiscriminatory basis religion, sex, age, marital status, or handicap.

pasture or hay for livestock purposes; and thirdly, these lands could be returned to crop production. Management of CRP returning to crop production after the contracts expire will require careful attention. Since these lands were eroding before program implementation, management systems that prevent soil erosion will need to be used.

Jastrow (2) in a prairie restoration study found that a grass-legume mixture caused greater aggregate stability, which is a measure of improved soil structure, when compared to a grain or root crop. Bushnell (3) estimated that 6 to 16 years were required for sod to beneficially rebuild soil tilth in a Wooster silt loam. Since CRP is a 10-year program, there should be beneficial contributions to soil structure from the sod management. Although soil structure may improve with a 10 year sod culture, soil physical properties will probably change again when cropping is resumed. This rate of change may also be affected by tillage management. The objectives of this research were to determine the effects of tillage systems on productivity and soil erodibility on an eroded landscape after long-term sod management.

MATERIALS AND METHODS

Plots were initiated on an established alfalfa (*Medicago sativa* L.)-smooth bromegrass (*Bromus inermis* Leyss.) stand near White, SD. The trial site is located on Wisconsin age Tazewell sub-stage glacial till in a Poinsett (fine-silty, mixed Udic Haploboroll)-Kranzberg (fine-silty, mixed Udic Haploboroll)-Waubay (fine-silty, mixed Pachic Udic Haploboroll) soil association. The trial site had heen in an alfalfa-bromegrass mixture for six years. This site was not a true CRP planting, but was considered to simulate conditions that would be present in CRP. Experimental design consisted of four replicates with seven treatments in a randomized block design. Tillage treatments consisted of fall moldboard plow, spring disk (MP), fall chisel plow, spring disk (CP), and no-till (NT90) established in 1990. Additional treatments were no-till (NT91) established in 1991, no-till (NT92) established in 1992, no-till (NT93) established in 1993, and a grass check (GC) of the undisturbed alfalfa-bromegrass sod. A continuous corn (*Zea mays* L.) rotation was grown on all treatments. Plot direction and all field operations ran up and down slope over a landscape continuum consisting of the shoulder, backslope, and footslope positions. Plot were 12.2 m wide which accommodated 16-0.76 m, rows. Plot length ranged from 110 to 158 m for the various replications. Variable plot lengths were require to obtain the three landscape positions in each replication.

The sod was killed one week before planting in 1990 by application of chemical herbicides. Sod in the subsequent no-till plantings was killed in the fall. Standard insecticides and pre-emergence herbicides were applied for insect and weed control. In 1991, 1992, and 1993 grass problems developed later in the growing season on the no-till treatments and additional post-emergence herbicide application was applied to the no-till treatments. The CP and MP treatments were cultivated twice during the growing season. In 1990, the NT90 treatment was cultivated once because of poor chemical weed control. Fertilizer nitrogen and phosphorus was applied based on South Dakota State University soil test recommendations for a corn yield goal of 9 Mg ha^{-1}. Plots were planted with a commercial four-row planter equipped with fluted coulters in 1991. An eight-row planter was used in subsequent years. Planting rate was 65,000 plants ha^{-1}.

A 12.2 by 12.2 m grid was developed on each replication for determination of depth of the mollic epipedon which is an estimate of topsoil development. Mollic colors have moist values and chromas ≤ 3.5. Mollic depth were placed into three depth categories: <25 cm, 25-35 cm, and > 35 cm. These mollic depth categories were generally associated with landscape positions and soil series with the shoulder having <25 cm, the backslope 25-35 cm, and the footslope >35 cm. Soil series correlation with landscape position were: eroded phase of Poinsett or Kranzberg on the shoulder position, Poinsett or Kranzberg on the backslope, and Waubay on the footslope. Major difference between the Poinsett and Kranzberg series was depth to change in parent material from silty drift to glacial till. This change occurred in the Poinsett series at 122 cm and at 105 cm in the Kranzberg series. Yield samples were taken in association with the grid points. In 1990, yield sample length was 24.4 meters. Subsequent harvest sampling was done on 12.2 m increments. Two rows were harvested with a commercial picker-sheller with three suhsamples within each harvest increment.

In 1993 after planting, rainulator trials with a Meyer-McCune type rainulator (4) were conducted to determine soil erodibility. Plots initially selected for investigation were: MP, NT91, NT93, and GC. For this series of rainulator runs, we choose to use the NT91 treatment because the NT90 was cultivated in 1990. This combination of treatments provided the extremes in tillage systems and the opportunity to observe changes that occurred within the no-till system with time. Three series of rainulator runs on these treatments where made on the Poinsett soil series in the upper or lower hackslope positions. A fourth series of rainulator runs were then made on the MP, CP, NT90, and NT92 treatments, on the Poinsett soil series. Each rainulator run consisted of a dry run on antecedent moisture conditions for a period of 60 min. A second run (wet run) was then made a minimum of 6 hours later, but most commonly the next day. Artificial rainfall was applied at a rate of 63.5 mm hr^{-1}. Plot size for the rainulator runs was 3 m wide by 10.6 m long, containing four planted rows and including one wheel-tracked interrow. Time to start water runoff and rates of water runoff and soil loss were measured. Time domain reflectometery (TDR) probes (5) were installed at the upper ends of the rainulator plots at depths of 10 and 40 cm for observations of soil moisture contents at five min time intervals.

RESULTS AND DISCUSSION

Soil productivity

Tillage system effect on corn yield is shown in Table 1. Yield differences among tillage systems were not significant ($p < 0.05$) in 1990 and 1991. Significant differences were observed in 1992 and 1993, hut these differences are strongly associated with growing season weather conditions. The cropping seasons of 1992 and 1993 can be characterized as stress years due to frost, cool growing season temperatures, and/or excessive precipitation. Growing degree days (GDD) were reduced 21 and 14% from the long-term average for the 1992 and 1993 cropping seasons. The 1992 corn crop was severely frost damaged in late May and subsequent development was retarded throughout the remaining season. The 1993 season was a year of excessively high precipitation and cool temperatures which resulted in slow plant development. In both season, the corn plants were killed by fall frost at or before kernel dent development. The effect of these growing season weather conditions reduced yields on all treatments, but the effect was most pronounced on the no-till treatments. A yield increase was observed for the first year no-till corn introduced in 1991, 1992, and 1993. As a general rule, corn grown in rotation yields 10% higher than continuous corn.

Table 1 Tillage system effect on corn yield

Tillage	Corn Yield (mg ha^{-1}) 1990	1991	1992	1993
MP	7.2	9.0	4.0	3.7
CP	6.9	9.0	3.7	3.5
NT90	6.5	8.9	3.3	2.7
NT91	-	10.2	3.5	2.8
NT92	-	-	4.1	2.6
NT93	-	-	-	3.4
P>F	0.08	0.06	0.002	0.001

Mollic depth had no significant effect ($p < 0.05$) on yield (Table 2). Mollic depth is strongly associated with soil productivity in soils developed in glacial till, but to a lesser extent in loess derived soils (6). The relationship between mollic depth, soil productivity, and long-term sod management was difficult to determine from these trials. Mollic depth influence on crop productivity would primarily be in water holding capacity and plant nutrient supply. Fertilizer application based on South Dakota State University soil test recommendation and ample precipitation during the study period corrected deficiencies that could be attributed to variation in mollic depths. The change in soil physical properties due to the sod culture may have changed soil productivity, but the change was constant across all mollic depths.

No-till corn production from this sod culture was comparable to the more intensively tilled management systems. However some problems were observed with no-till and will need to be addressed. Chemically killing of the sod was not always completely effective which resulted in severe weed pressures in some years and required additional herbicide applications. This was true for the no-till initiated in 1990 when the sod was killed one-week before planting. Better results were obtained in later years when the sod was killed the previous fall. Soil incorporated herhicides are not compatible with no-till; therefore, weed control is dependent on surface applied pre-emergence and post-emergence herbicide. Cultivation during the growing season may be an option, but this operation will require a specially designed cultivator to handle heavy surface residues and will disrupt soil structure in the cultivated zone.

Table 2 Mollic depth effect on corn yield

Tillage	Corn Yield (mg ha^{-1}) 1990	1991	1992	1993
<25	6.9	9.1	3.7	3.0
25-35	6.8	9.4	3.8	3.2
>35	6.9	9.4	3.7	3.1
P>F	0.99	0.80	0.44	0.25

Soil erodibility

Time to start runoff, runoff expressed as percent of applied rainfall, and soil loss are shown in Table 3 for the dry and wet runs. Water runoff was not observed for the GC or any of the no-till treatments in either the dry or wet runs. This lack of runoff suggests a stable surface structure capable of infiltrating the applied rainfall and transporting the applied water into and through the soil profile. Soil structure that developed during sod culture has been maintained with no-till management. This is evident from the lack of water runoff that was measured in the NT90 treatment, which was in the fourth year of continuous corn production and had been cultivated once to a depth of 7.5 cm in 1990. Water runoff and soil loss was observed with both the CP and MP treatments. Both treatments were in the fourth year of continuous corn production. Direct comparisons between these treatments should be made with caution, because only one run was made on the CP treatment as compared to the average of four runs on the MP treatment. Slope gradients ranged from 5.4% to 3.5% for the MP treatment runs and was 3.1% for the CP treatment run. Surface residue coverage was 25% for CP compared to 3% for MP. The high runoff and soil loss amounts observed with the MP show that a highly erodible condition can rapidly be obtained after sod management with intensive tillage. The reduction in soil erodability with CP can be attributed somewhat to surface residue coverage, but may also be related to less disruption of soil structure by the less intensive tillage system.

Table 3 Time to start runoff, runoff expressed as percent of applied rainfall, and soil loss

Treatment	Dry Run			Wet Run		
	Runoff start (min)	Runoff (%)	Soil loss (kg ha^{-1})	Runoff start (min)	Runoff (%)	Soil loss (kg ha^{-1})
MP	9	26	8500	1	72	20400
CP	3	19	2200	2	34	3600
NT90	>60	0	0	>60	0	0
NT91	>60	0	0	>60	0	0
NT92	>60	0	0	>60	0	0
NT93	>60	0	0	>60	0	0
GC	>60	0	0	>60	0	0

Changes in soil water content with applied rainfall for one replicate during the wet run at 10 and 40 cm depths for selected treatments as measured by TDR are shown in Table 4. The wetting front was quickly observed at 10 cm for all treatments. At 40 cm, the wetting front was observable in the NT93 treatment within 5 min. The advance of the wetting front at 40 cm was slightly faster in the CP treatment than with the MP treatment and the time required to reach maximum soil water content was also faster with CP than with MP. Drainage (data not shown) at 10 cm was again rapid after completion of the wet run for all treatments. Drainage at 40 cm began shortly after completion of the wet run for the NT93 treatment. Drainage in the CP treatment commenced shortly after maximum soil water content was reached, whereas, drainage in the MP treatment was delayed and drained at a slower rate. While not a direct measurement, the wetting and drying patterns suggest better soil pore continuity between surface and subsurface soil layers with the no-till than with the tilled treatments. The pore continuity appeared better for the CP than for the MP treatment.

CONCLUSIONS

No-till management was an acceptable management option for erodible lands that had been in long-term sod. Continuous corn yields with no-till were comparable with yields obtained with the more intensive tillage systems, even though weed control was a problem and required special attention. The relationship between mollic depth, soil productivity, and long-term sod management could not determined in the this study. Soil erodability after sod was lowest with no-till. Beneficial soil structure that developed during the sod management period allowed rapid water movement into and through the soil profile and was maintained with no-till through four cropping seasons.

Table 4 Observation of wetting front movement for selected treatments during the wet run

		Time (min.)		Water Content (m^3 m^{-3})	
Treatment	Depth (cm)	Change[a]	Max[b]	Start[c]	Max[d]
MP	10	<5	50	0.34	0.41
	40	50	100	0.32	0.35
CP	10	<5	45	0.38	0.43
	40	45	90	0.35	0.38
NT93	10	<5	55	0.33	0.37
	40	5	60	0.30	0.33

[a] Time from start of wet run to observable soil water content change.
[b] Time from start of wet run to maximum soil water centent.
[c] Soil water content at start of wet run.
[d] Maximum soil water content reached with applied rainfall.

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EFFECTS OF REDUCED TILLAGE PRACTICES ON SOIL QUALITY IN EASTERN QUEBEC

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ABSTRACT

In addition to reducing soil erosion and production costs, the adoption of reduced tillage practices in cereal monoculture can modify the chemical, physical and biological properties of surface soils. In three field experiments conducted on clay soils in Eastern Québec, soil water-stable aggregation and selected organic matter characteristics were measured periodically to characterize the tillage-induced changes in soil quality. Water-stable aggregation and soil organic matter quality changed rapidly when different tillage practices were implemented. For example, differences in soil aggregation and infiltration rate between no-till and moldboard plowing were observed after only one year. The tillage-induced differences in aggregation which increased with time, were correlated with labile organic matter fractions such as microbial biomass and soluble carbohydrates. Tillage had little effect on total organic matter content of the plow layer.

INTRODUCTION

Soil quality can be defined as the ability of the soil to perform three critical functions: i) provide a medium for plant growth, ii) regulate and partition water and gas flow through the environment and iii) serve as an effective environmental buffer (Acton 1993). Larson and Pierce (1992) suggest that soil quality can be measured by selection of key indicators (minimum data set) such as texture, organic matter, pH, nutrient status and soil structure. Among those properties, both soil organic matter (SOM) and soil structure are likely to be influenced by tillage practices.

Although it is well documented that tillage practices such as moldboard plowing result in a dilution of the SOM in the plow layer, there is still controversy as to extent to which tillage actually alters SOM turnover and composition. Soil organic matter quality can be characterized using a minimum data set as proposed by Gregorich et al. (1994). Microbial biomass carbon and light- or macro-organic matter have been suggested as early indicators of management-induced changes in total SOM. Labile carbohydrates can also be used for the same purpose as well being indicative of changes in aggregate binding agents. The extent to which tillage alter these proposed early indicators of SOM quality needs to be determined under varying soil and climatic conditions.

Kay et al. (1988) proposed the concepts of structural form and stability. Soil structural form can be defined as the spatial arrangement of pores and solids whereas structural stability refers to the the resistance of this arrangement to external stresses. Structural form can be characterized using porosity and its related properties and stability using various measurements of aggregate stability. Although the effects of tillage on soil structure have been studied extensively, the results obtained were often contradictory both in terms of structural form and stability.

The fine-textured soils of the St. Lawrence lowlands often exhibit signs of structural deterioration in the form of surface crusting and a dense massive plow layer. A recent survey of the problems of soil degradation in agricultural soils of Québec has shown that more than 80% of the soils under monoculture show signs of structural degradation relative to adjacent soils under perennial forages (Anonymous 1990). The purpose of this communication is to present data from three experiments in which soil quality has been intensively characterized in terms of the preceeding parameters. We concentrate on short-term effects (< 10 years) as it is assumed that information on changes in soil conditions induced by management practices must be appropriate for the farmer's planning horizon, i.e. the extent of change which can be expected within a few years (Kay et al. 1988).

MATERIALS AND METHODS

Three field experiments were established in three locations of Eastern Canada. They were all conducted on poorly-drained soils characteristic of the local conditions. In general, the climate of the region is cold and humid with a short growing season.

Experiment 1. La Pocatière

The experiment was located at the Agriculture Canada Experimental Farm in La Pocatière, Québec, Canada on a Kamouraska clay (Orthic Humic Gleysol). The particle size distribution of the surface horizon (0-20 cm) at the site is 10% sand, 30% silt and 60% clay. The experiment was a split-plot with 4 replicates with crop rotations as the main-plot treatment and tillage practices as the subplot treatment. Only the data pertaining to the continuous barley system is presented here. The three tillage treatments consisted of 1) fall moldboard plowing (15-18 cm) with spring secondary tillage, 2) fall chisel plowing (12-15 cm) followed by spring secondary tillage, and 3) no-tillage. Spring secondary tillage for both MP and CP consisted of one or two passes of a rigid-tooth finishing harrow. Other management practices are described by Angers et al. (1993a). Barley yields averaged 3000 kg dry matter ha^{-1} yr^{-1} and were not affected by tillage. The experiment was initiated in 1987 and soil samples were taken in 1992.

Experiment 2. Normandin

The study was initiated in 1991 on a Normandin silty clay (Humic Gleysol) at the Agriculture Canada Experimental Farm in Normandin, Québec, Canada. The particle size distribution of the surface horizon (0-20 cm) at the site is on average 10% sand, 40% silt and 50% clay. The experiment consisted of a comparison of four tillage treatments in a barley monoculture production system. The tillage treatments were 1) no-till, 2) harrowing in the spring, 3) chisel in the fall + spring harrowing, and 4) conventional moldboard plowing in the fall + spring harrowing. Barley yields averaged 4000 kg dry matter ha^{-1} yr^{-1} and were not affected by tillage. Soil samples were taken in 1992.

Experiment 3. St-Lambert

The experiment was performed on a Neubois silt loam (Gleyed Humo-Ferric Podzol) located at the Québec Ministry of Agriculture Experimental Farm in St-Lambert, Québec, Canada. The texture of the Ap horizon (0-24 cm) was 23% clay, 50% silt and 27% sand. The experimental design was a randomized complete block with three treatments and four replicates. The three treatments were 1) minimum tillage which consisted of two passes of a field cultivator (spring tines) in the spring, 2) ridge tillage in which ridges (15 cm high) were reformed each spring before planting, and 3) moldboard plowing (18 cm) in the fall followed by harrowing in the spring. The experiment was initiated in 1978 on a soil previously under permanent meadow, and the soil was continuously cropped to silage corn using management practices as recommended in Québec. Silage corn yields averaged 9.5 Mg dry matter ha^{-1} yr^{-1} and were not influenced by tillage. The soil samples were obtained in 1987.

Soil sampling and analyses

Soil samples were taken with a spade from varying soil depths depending on the experiment. Three random subsamples were taken per plot (replicate) and soil depth. The three subsamples were bulked, passed through a 6-mm sieve and kept at 4°C until analysis.

Microbial biomass C (MBC) was determined using a modification of the fumigation-extraction procedure, and carbohydrates were determined in two types of soil extract: hot-water-soluble carbohydrates (WSC) and acid-hydrolysable carbohydrates (AHC) (Angers et al. 1993a). Macroorganic matter was determined after disruption and dispersion of the soil by sonification (Angers et al. 1993b) and is represented by the sieved fraction > 50 μm. Organic C in whole soils and soil separates was measured by wet oxidation.

The size distribution of water-stable aggregates was measured by spreading 40 g of field-moist soil (<6 mm) on the top of a nest of sieves with openings of 2, 1, 0.5, and 0.25 mm. The aggregates were wetted by direct immersion. Wet sieving was performed as described by Angers and Mehuys (1993). Aggregate mean-weight diameter (MWD) was calculated. Soil water content was determined gravimetrically. Infiltration rate was estimated in the field using a single-ring (18 cm diameter) at a constant head of 10 cm.

RESULTS AND DISCUSSION

Soil structure

Tillage treatments induced surprisingly rapid changes in water-stable aggregation. Only one year after the implementation of the experiment, significant differences in MWD were observed between the tillage treatments in Normandin. In general, MWD increased as tillage intensity decreased (Table 1). Changes in aggregation were mostly apparent in the macroaggregate fraction (1 to 6 mm) (data not shown). These tillage-induced differences in aggregation resulted in corresponding changes in infiltration rate (Table 1). Infiltration rate and MWD were positively correlated ($r = 0.93^{**}$).

Table 1. MWD of water-stable aggregates and infiltration rate as influenced by tillage practices at Normandin. Samples (0-8 cm depth) for MWD and field measurements of infiltration taken in the second year of the experiment (June 1992).

Tillage treatment	MWD	Infiltration rate
	mm	cm hr^{-1}
No-till	2.18	3.2
Harrowing in spring	2.02	2.1
Chisel (fall) + harrow (spring)	1.98	1.5
Plowing (fall) + harrow (spring)	1.75	0.7
Protected-LSD	0.30	1.1

Soil organic matter

Measurements of SOM quality made during the fourth year of the experiment at the La Pocatière site showed a significant impact of tillage on total organic C, MBC and carbohydrates (Table 2).

Table 2. Effects of tillage on SOM quality and water-stable aggregation (MWD) at la Pocatière in the fourth year of the experiment (0-15 cm).

Tillage	Org. C	MBC	WSC	AHC	MWD
	kg C m^{-2}	--------- %	of total organic C	--------	mm
Plowing	4.9	1.2	0.54	9.1	2.1
Chisel	5.8	1.4	0.56	9.3	2.0
No-till	5.8	1.6	0.64	10.5	2.5
Prot.-LSD	0.4	0.2	0.04	0.6	0.3

The lower content of C in the plowed soil may be the result of accelerated oxidation but also of dilution of the SOM in the soil profile as plowing was performed at 18 cm. As a proportion of total C, MBC and both carbohydrate fractions were more abundant in the no-till soil than in the other treatments. This suggests that no-till altered SOM quality by increasing the proportion of labile SOM relative to conventional tillage.

A correlation analysis was performed at the la Pocatière site to study the relationships between SOM quality and soil structure. Both MBC and carbohydrates, but not total C, were significantly correlated ($P < 0.05$) with MWD which suggest that these labile fractions contribute to changes in aggregation before changes in total SOM can be observed.

The results of St-Lambert show that 10 yr of different tillage practices did not result in significant differences in total organic C when the whole plow layer was considered (Table 3). However, MBC, macro-organic matter and aggregate stability were positively affected by conservation tillage.

Table 3. Effects of 10 yr of tillage practices on SOM quality and stable aggregation (0-24 cm)

Tillage treatment	Organic C	MBC	Macro-OM	WAS[1]	Proportion of C derived from corn[2]
	kg C m^{-2}	% of total organic C		%	%
Superficial	7.6	4.2	11.0	82	6.5
Ridge	7.4	3.0	13.4	74	7.7
Plowing	7.4	1.3	7.5	65	7.6
Prot.-LSD	NS	0.20	2.8	6	NS

[1] WAS = Wet-aggregate stability.
[2] Calculations based on $\delta^{13}C$ natural abundance.

The St-Lambert experiment also provided an opportunity to investigate the effects of tillage on SOM turnover using δ^{13} C as a natural SOM tracer. The results (Table 3) suggested that 10 years of different tillage practices did not significantly alter the turnover of SOM as expressed by the proportion of C derived from corn. These results also confirmed that the turnover rate of SOM in these cool and poorly-drained soils is relatively slow.

CONCLUSION

Water-stable aggregation and soil organic matter quality changed rapidly when different tillage practices were implemented. For example, differences in soil aggregation and infiltration rate between no-till and moldboard plowing were observed after only one year of experiment. The tillage-induced differences in aggregation increased with time and were correlated to the labile organic matter fractions such as microbial biomass and soluble carbohydrates. Tillage had little effect on total organic matter content.

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RECONSOLIDATION OF A DEEP-LOOSENED SILT LOAM UNDER PLOWING AND CONSERVATION TILLAGE

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ABSTRACT

Compaction zones below actual plowing depth may lower soil productivity and plant performance. We tested the hypothesis that the subsoil, strip loosened by the paraplow and the slit plow, will recompact less readily under conservation tillage than under plowing. The hypothesis was confirmed in the field by soil physical and biological investigations, by plant parameters as well as a new method of characterizing soil structure by X-ray radiographs.

INTRODUCTION

In many plowed soils of Germany pan formation and subsoil compaction have resulted from excessive use of heavy machinery. Efforts to reloosen the compacted layers in total by mechanical devices often failed. Because of lowered shear strength ameliorated soils may recompact readily and to a higher extent than before. Both the paraplow developed in England (1) and the slit plow (2) from East Germany however, will loosen the subsoil not across total working width but only within strips, leaving firm areas in between (Fig. 1).

We hypothesized that the strip loosened soil will recompact less under conservation tillage than under conventional mouldboard plowing.

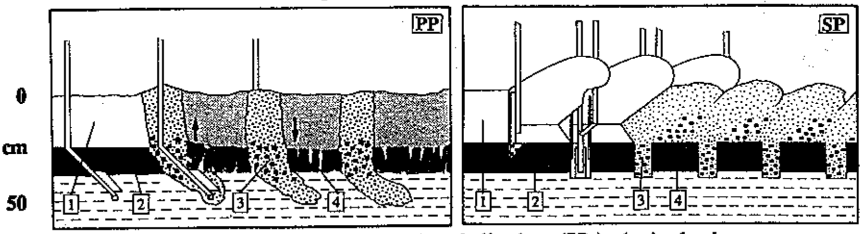


Fig. 1: The mechanical effect of paraplow (PP) and slit plow (SP:) 1. A_p-horizon, 2. traffic pan, 3. loosened area, 4. firm area, ↑ or ↓ direction of soil movement

THE FIELD EXPERIMENT

We tested the hypothesis on grey brown podzolic soil derived from loess (Typic Hapludalf) at the northeastern rim of the Solling mountains (190 m, 8,2°C, 809 mm). The two-factorial field trial with four replications was started in September 1990 (Table 1).

After paraplowing to 50 cm depth, the treatment PP/PL was mouldboard plowed. By use of the slit plow (45 cm) on the other hand, the top soil was inevitably turned (Fig. 1), thus submitting SP/PL as well as SP/CS to identical conditions during the 1991 season. Apart from this peculiarity at the experimental start, conservation tillage means the regular application of the rotary harrow for seedbed preparation and stubble cultivation (8-10 cm). The depth of plowing is 25 cm. In 1990/91 winterwheat was grown, followed by sugarbeet (1992) and winterwheat again (1992/93).

Table 1: The combination of the two factors (deep loosening and topsoil cultivation) results in six treatment combinations:

1. Factor: deep loosening (only once in 1990)	2. Factor: topsoil cultivation (every year) Plowing PLOW (PL)	Conservation tillage CONS (CS)
No deep loosening (NL)	NL/PL	NL/CS
Paraplow (PP)	PP/PL	PP/CS
Slitplow (SP)	SP/PL	SP/CS

RESULTS AND DISCUSSION

Deep loosening increased wheat yield slightly in 1991 ($p = 0.25$) and sugar yield significantly in 1992 ($p = 0.05$), but hardly wheat yield in 1993 (not significant) (Table 2). Conservation tillage favored wheat yield in 1991 not significantly and in 1993 slightly ($p = 0.25$), whereas sugarbeet benefited by plowing ($p = 0.01$). There were no significant interactions.

Table 2: Yield of winterwheat (grain) and sugarbeet (purified sugar)

		Treatment					
		NO DEEP LOOSENING		PARAPLOW		SLIT PLOW	
Crop	Year	PLOW	CONS	PLOW	CONS	PLOW	CONS
		.... Mg ha^{-1}					
Winterwheat	1991	7.1	7.3	7.2	7.4	7.8	8.0
Sugarbeet	1992	8.5	7.0	8.8	8.1	9.2	8.4
Winterwheat	1993	6.6	6.5	6.6	7.1	6.5	6.8

Within the area of the subsoil, cultivated by the slant leg (Fig. 1) of the paraplow (PP), bulk density (BD) decreased in October 1990 as compared to the firm area and to the soil not deeply loosened (NL) (Fig. 2). In the slots of the slit plow (SP) the soil was broken up too (Fig. 2). Only two years later, in October 1992, the loosened and partly the firm areas of PP and SP had reconsolidated under the impact of plowing. With conservation tillage as a form of firm soil husbandry, recompaction was much lower (Fig. 2).

Within the soil layer below actual tillage depth, BD reached the original value of 1,55 g cm^{-3} not later than one or one and a half years after deep loosening (Fig. 3). The soil recompacted readily under the action of plowing, whereas with conservation tillage BD of the loosened area remained in the range of 1.37 (SP) to 1.44 g cm^{-3} (PP), even two years after the experimental start.

The change in BD modifies the hydraulic conductivity function: We evaluated the unsaturated conductivity (K_u) at a soil moisture tension of 30 and 100 hPa (3), corresponding to an effective pore diameter of 100 and 30 μm. By subtracting the lower K_u (at 100 hPa) from the higher K_u (at 30 hPa) the "specific K_u" of the 30-100μm pore class was determined (Fig. 4). Paraplowing increased "K_u" in the loosened area (May 1991). But plowing the topsoil depressed "K_u" within a year (May 1992), going along with an increase of BD

(Fig. 2 and 3). On the contrary conservation tillage kept "K_u" on a high level in the loosened area of PP and induced an increase of "K_u" in the firm area. "K_u" increased also in the soil not deeply loosened (Fig. 4), an effect probably caused by roots.

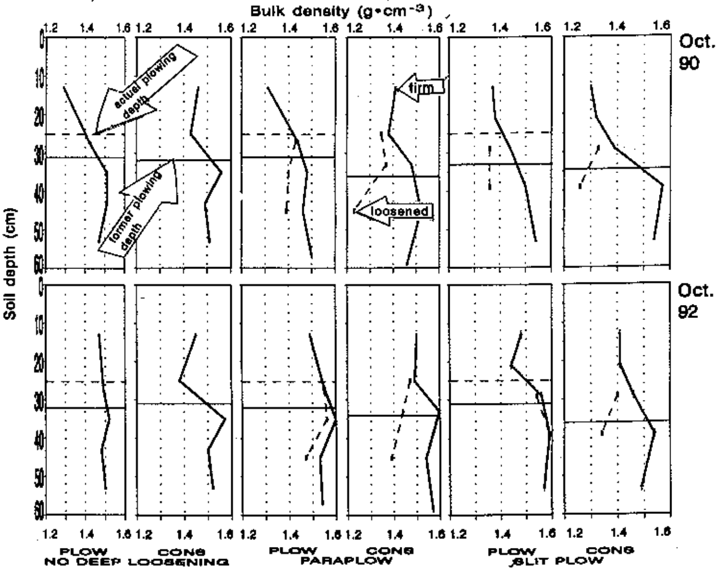


Fig. 2: Effect of deep loosening and top soil cultivation on bulk density profiles in two years. Beside the actual plowing depth (25 cm) the depth of the Ap-horizon originating from former plowing is also indicated. This depth is slightly variable at the site

Like "K_u", root growth of sugar beet (profile wall method) in the subsoil was enhanced by conservation tillage (Fig. 5), an effect independent of deep loosening. Old compacted and newly recompacted layers below actual tillage depth (Fig. 2) obstructed deep rooting and concentrated roots in 20-25 cm depth (Fig. 5).

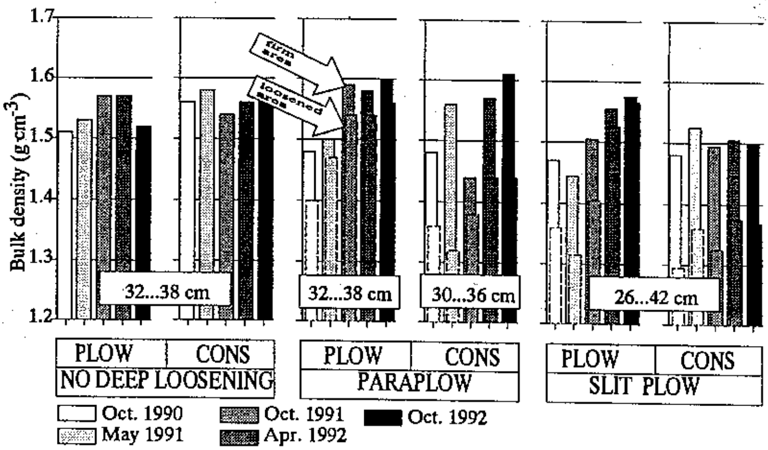


Fig. 3: Bulk density below actual plowing depth at five dates from start of the experiment, as affected by deep loosening and top soil cultivation

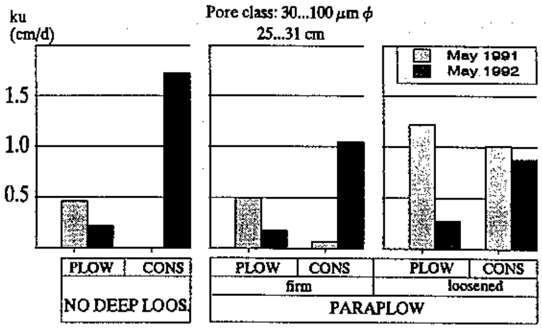


Fig. 4:
The specific unsaturated hydraulic conductivity "K_u" (cm day^{-1}) of the pore class 30-100 μm below actual plowing depth, as affected by paraplowing and top soil cultivation

Similarly, earthworm activity (formalin method) was favored by conservation tillage, whereas plowing had a detrimental effect (Fig. 6). Detrimental was deep loosening too. Under conservation tillage the number of animals per area increased slightly from 1991 to 1992, but with plowing the number came down. The frequency of earthworm channels near the soil surface was generally related to the activity (Fig. 6).

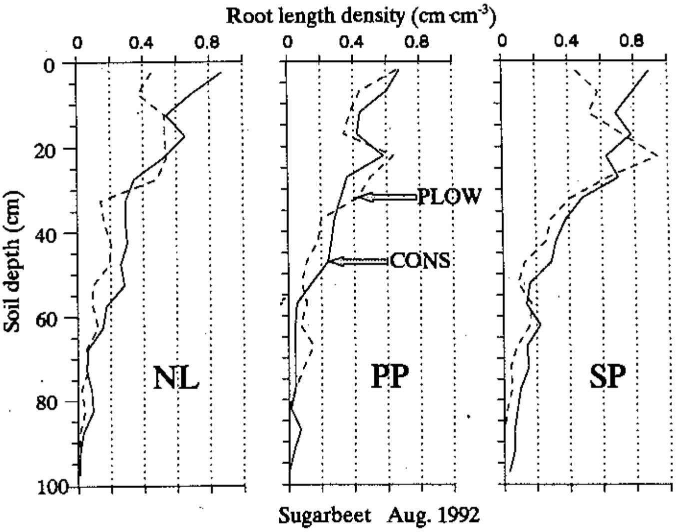


Fig.5:
Profiles of root length density as affected by deep loosening and top soil cultivation under sugarbeet

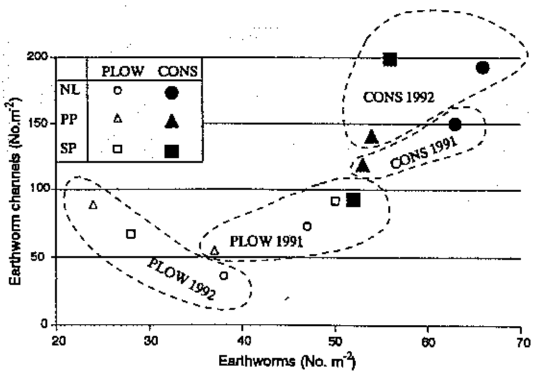


Fig. 6:
Earthworm activity and number of channels per area (5 cm depth) as influenced by deep loosening and top soil cultivation in two years. Note that in 1991 SP/CS necessarily was plowed

The change in soil structure was evaluated by X-ray radiographs of undisturbed soil samples (90x60x10 mm), taken laterally from the soil profile (4). These radiographs are projections of X-ray attenuation. Provided that energy of radiation, sensitiveness of X-ray film, soil composition and thickness of the sample are the same, a close relationship will exist between the density (degree of opacity) of the negative and the arrangement of soil particles. After scanning and digitizing of X-ray negatives a correlation was found between the mean grey value of a digitized X-ray image and the mean BD of a soil sample. Based on these findings we will transform within one sample the spatial arrangement of image sectors into definable areas of different BD.

Fig. 7 illustrates the distribution of BD within the firm and loosened area of the two paraplow treatments. In May 1991 the firm area is represented by fractions of high BD between 1.5 - 1.7 g cm^{-3} (top, left). In the loosened area the fraction of lower BD has increased (top, right), probably by creation of interaggregate space. In October 1992 the BD-distribution has markedly changed: Under the action of plowing in the firm (bottom left) and loosened area (bottom right) fragments are created with higher BD than measured before. Such kind of recompaction is avoided under conservation tillage, where most of the soil fragments arrive at BD between 1.3 - 1.6 g cm^{-3}.

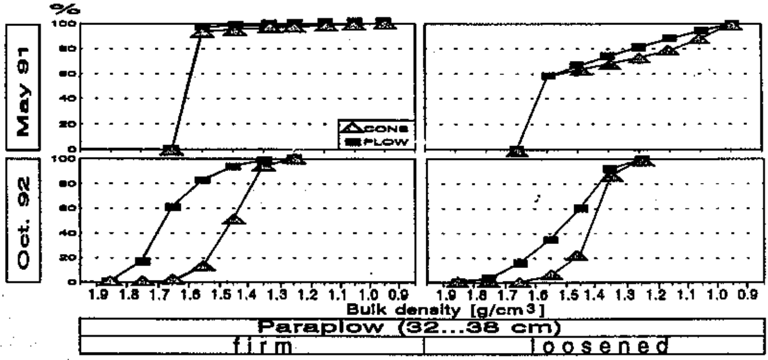
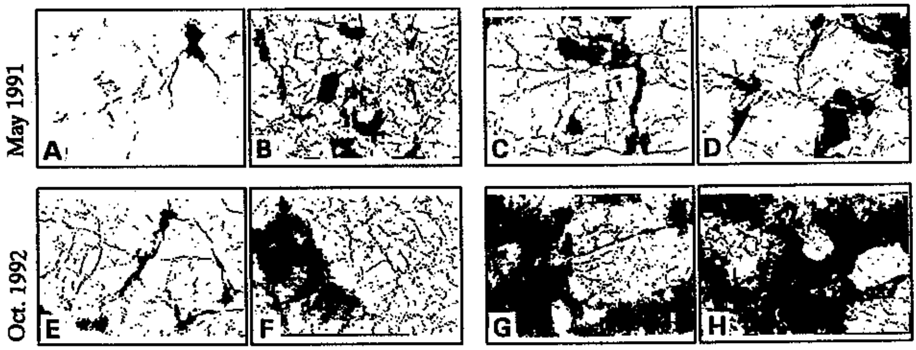


Fig. 7: Bulk density distribution derived from grey shading of digitized radiographs



PARAPLOW (32...38 cm)			
PLOW		CONS	
firm	loosened	firm	loosened

Fig. 8: Generating secondary images by skeletonization and binarization of digitized radiographs. Areas of low bulk density appear dark

In order to evaluate geometrical properties of soil structure (Fig. 8), parameters of image processing have been derived, based on procedures of skeletonization, binarization and direction coding. Initially (May 1991) the firm areas of PLOW and CONS are characterized by a massive structure with some fissures and vesicles or by a platy structure with crevices preferably in horizontal direction (Fig. 8, A and C). Mechanical loosening changed the compact into a fragmental structure with vughs and a fine or coarse pattern of curved or linear fissures. Some of the coarse fragments seem to be distorted (B and D). By October 1992 conservation tillage has induced low-density-zones both in firm and loosened areas. Structural units show rugged faces and increased internal pore space (Fig. 8, G and H). On the contrary, mouldboard plowing is lacking a distinct structural development (E and F).

Quantitative parameters of image processing are area of contour (black image objects), length of contour, form factor (which describes independently of size the deviation from a circle by a number > 125) (Table 3) and finally the orientation of linear image elements. Note that area and length of contour increase significantly only with CONS between the years. Correspondingly the highest form factor is evaluated in the loosened area of CONS. Results of direction coding are unobtrusive. The small preference of horizontal orientation in case of CONS might be a consequence of mechanical stress.

		PARAPLOW (32...38 cm) PLOW		CONS	
		firm	loosened	firm	loosened
May 1991	· area of contour (%):	1.5	7.6	5.9	13.9
	· length of contour (NP):	158	1546	1104	1437
	· formfactor:	276	313	362	328
	· orientation distribution based on direction coding vert. (%):	34	27	24	23
	hor. (%):	24	30	31	33
Oct. 1992	· area of contour (%):	3.7	5.8	40.9	57.3
	· length of contour (NP):	900	1192	2410	2748
	· formfactor:	353	350	329	585
	· orientation distribution based on direction coding vert. (%):	28	27	26	25
	hor. (%):	28	27	27	33

Table 3: Characteristics of secondary images, shown in Fig. 8 (NP = number of pixels)

CONCLUSION

Under the conditions of practical farm management, plowing caused a rapid reconsolidation of the subsoil, which had been ameliorated previously by two forms of strip loosening. Under the safeguard of conservation tillage soil structure was stabilized and transmitting properties were improved by enhanced biological activity. We conclude that mechanical strip loosening may be a starting point for conservation tillage on heavily compacted soils.

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HARDPAN AMELIORATION AND REDEVELOPMENT IN LOAMY SAND UNDER A ZERO TRAFFIC SYSTEM

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ABSTRACT

The consequences of six ripping treatments (ripped 1982, 1984, 1986, 1988, 1991 and 1993) and one no-ripping treatment without subsequent traffic, were examined over three growing seasons (1991 to 1993) on a loamy sand. Measurements included penetration resistance, water content, bulk density and the determination of grain yield of wheat. The effects of ripping on bulk density were significantly different with respect to the unripped treatment for only two years after ripping. Penetration resistance increased with time after ripping and reached a plateau value after 7 to 8 years, generally remaining lower than for the unripped plots. Accordingly, grain yields remained significantly higher after ripping, with the greatest differences being observed in the first few years.

INTRODUCTION

With the increasing usage of heavy agricultural machinery on Australian farms, more powerful tools have been developed to facilitate subsoiling or deep ripping to a degree that was not previously required. Most deep ripping of Western Australian wheatbelt soils is carried out using either an Agrowplow or an Ausplow (Jarvis, 1992). These tillage tools have narrow tines, each equipped with a seven centimetre wide flat blade which operates at around eight degrees above the horizontal. Additionally, each tine has a hydraulic release in case immovable objects are encountered. The standard tine spacing on the Agrowplow is 330 mm, and 460 mm on the Ausplow (Jarvis, 1992). Both implements are up to nine metres wide. Many experiments in Europe (Andersson and Håkansson, 1963; van Dam, 1975), North America (Fritton and Olson, 1972; Côté and Dupuis, 1980) and Australia (Ellington, 1986; Daniel et al., 1988), using these or similar techniques, have indicated that mechanical loosening of soil is in some cases unstable and of short duration.

For most agricultural soils of the Western Australian wheatbelt the maximum past consolidation stress would be much higher than the present overburden effective stress. Summer drying cycles common to the semi-arid W.A. wheatbelt will emphasise any processes which lead to overconsolidation, due to an increase in effective stress on soil fabric. In contrast, virgin soil is in void ratio equilibrium with the present overburden effective stress.

The field work presented in this paper examines the effects of deep ripping on soil resistance to penetration and crop yield, associated with subsequent consolidation and strength development on a loamy sand soil in the absence of further wheel traffic.

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MATERIALS AND METHODS

Site, climatic and soil conditions

The experiment was conducted between 1991 and 1993 at the Wongan Hills Research Station of the Western Australian Department of Agriculture as part of an ongoing deep ripping experimentation (trial code: 82WH49) commenced in 1982. Wongan Hills has an average annual rainfall of 345 mm and an average annual Class A pan evaporation of 2521 mm (Luke et al., 1987). The average growing season rainfall is 262 mm.

The soil is classified as a Typic Xeropsamment (Soil Survey Staff, 1975) and was similar to the loamy sand of an adjacent recompaction trial (trial code: 84WH3) described previously (Daniel et al., 1988). A hardpan had developed between 17 and 22 cm depth. Some physical properties of the soil are presented in Table I.

TABLE I

Soil physical properties

Depth (cm)	Particle size distribution (%, kg/kg)			Water content at field capacity (%, kg/kg)	pH (water)	Organic C (%, kg/kg)
	2000–63	63–2	<2 μm			
0–15	89	6	5	8	5.6	0.6
15–25	83	7	10	10	5.0	0.3
25–40	81	7	12	11	5.2	0.2

Treatments and measurements

In August 1982 experimental plots measuring 60 X 2.5 m were arranged in four replicate blocks. Each replicate two plots (representing subplots A and B for the particular treatment) were deep ripped (R82) to 300 mm using an Agrowplow. Of the remaining plots eight (four pairs of subplots A and B) were retained as controls (UR) in which the original hardpan remained intact and the others were retained for future ripping treatments. The only subsequent traffic allowed was a sprayer travelling at 90° to the orientation of the plots. All other operations, i.e. ripping, planting, and harvesting, were carried out by straddling the centre of the plots with the tractor.

Subsequently, similar ripping treatments to the one described above were conducted in April 1984 (R84), August 1986 (R86), May 1988 (R88), June 1991 (R91), and June 1993 (R93) on the plots retained for this purpose. The trial was kept under a two-pasture-years/two-crop-years rotation, with 1985/1986 and 1989/1990 as the pasture years. Twelve rows of wheat at 180 mm row spacing were sown on each subplot in each crop year. In 1992 lupins (*L. angustifolius* cv. Gungurru) were sown, followed by wheat in 1993.

Penetration resistances (P_{res}) were measured to 0.47 m depth using a Bush recording penetrometer (Anderson et al., 1980). Transects of 10 penetrometer probings were taken in randomly chosen areas of each of the subplots A at 0.2 m lateral spacing. The traffic lanes caused by the passes with a sprayer were noted and avoided for these measurements. At the same time the gravimetric soil water content was measured on subplots B using ring samples from a location adjacent to the penetrometer probings to 0.40 m depth at 0.05 m depth intervals per plot. Also on subplots B, soil cores with a diameter of 98 mm and a height of 100 mm were sampled from three positions per plot (R91, R88, R86, R82 and UR treatments only) to 0.35 m depth at 0.10 m vertical intervals, for the determination of bulk densities. Subplots A were particularly reserved for soil strength measurements, whilst on subplots B measurements were conducted which required the removal of soil samples. Soil strength and water content measurements were repeated throughout the growing season. The soil cores for bulk densities were sampled in March 1991 and February 1992. Additionally, to achieve a complete set of bulk densities with time after ripping, the R91 treatment was sampled in July 1991 (shortly after the ripping operation) and in July 1993.

A plot harvester was used to harvest 10 rows of wheat from the middle of each plot (subplots A only) for the grain yield determinations.

RESULTS AND DISCUSSION

Soil conditions

The deep ripping operation disrupted the hardpan at 17 to 22 cm depth. Subsequently, and in the absence of further wheel traffic, soil strength increased with time after ripping.

Penetration resistance (P_{res}) profiles from three dates (13 August 1991, 20 May 1992, and 16 July 1993) were taken for comparison. The soil water contents at the different dates were very similar, the averages at 15 to 20 cm depth being 5.8% (kg/kg), 5.4% (kg/kg), and 6.6% (kg/kg) respectively. Differences in soil water content between the treatments were very small and not significant. P_{res} values at 19 cm depth shortly after a ripping operation were 16% (R91 in 1991) and 17% (R93 in 1993) of that of the unripped (UR) treatment. At this depth the P_{res} values for one to eleven years after a ripping operation increased from 24% (R91 in 1992) to 70% (R82 in 1993) of that of the UR treatment (Fig. 1). It appears that the soil strength development did reach a plateau value after about seven years after the initial soil disruption, as the 1993 P_{res} values of the R86, R84 and R82 treatments were not significantly different. However, the reformed hardpan strength remained significantly below that of the never ripped treatment.

TABLE II

Bulk density at 15-25 cm depth with time after deep ripping (trial 82WH49)

Year sampled	Bulk density (Mg/m^3)				
	R91	R88	R86	R82	UR
1991	1.49[a]	1.66	1.65	1.67	1.68
1992	1.60[b]	1.65	1.67		
1993	1.63[b]				

[a,b] Different from UR at 1% level and 5% level, respectively (Duncan multiple range test).

Table II shows that the effects of ripping on bulk density were significantly different with respect to the unripped treatment for only two years after the ripping operation. In general, on these loamy sands bulk density appears to be a much less sensitive index to examine small property changes, as a result of a soil disruption or compaction, compared to a measure of soil strength, i.e. penetration resistance. This has also been observed at related field trials in Western Australia (Henderson, 1986).

By comparing the above results (trial: 82WH49) with those of an adjacent recompaction trial (trial: 84WH3) it is evident that, although both soils appear to be very similar in nature and both trial sites are in close proximity to each other (approx. one kilometre apart), the pattern of hardpan redevelopment contrasts markedly for these two soils (Fig. 1).

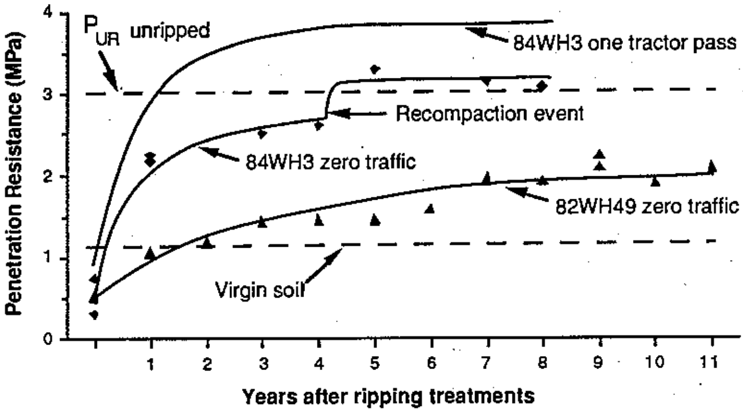

Fig. 1. Strength development with time with and without wheel traffic at 19 cm depth at different sites.

At trial 84WH3, four years after ripping, the P_{res} of the ripped/zero-traffic treatment had redeveloped to 89% of that of the never ripped UR treatment. Subsequently, a recompaction event equivalent to one pass of a 5.2 t tractor resulted in a further P_{res} increase to 105% of that of UR. The ripped/one-tractor-pass treatment (Fig. 1) indicates that soil structure is more damaged if the same level of traffic is applied immediately following a ripping operation, with P_{res} over the following years having redeveloped to 125% of that of UR. The data of trial 82WH49 indicate that, following a ripping operation and in the absence of further wheel traffic, soil structure appears to have stabilised after 7 years, with the P_{res} of the ripped treatments after this period not exceeding 70% of that of the never ripped UR treatment. The P_{res} level, at a soil moisture content of around 6% (kg/kg), of the UR treatment (P_{UR}) at 19 cm depth was about 3 MPa and similar for both experiments. Figure 1 clearly shows the much more rapid strength redevelopment of trial 84WH3. After only one year following soil disruption, the P_{res} at 19 cm depth has already reached 2 MPa which for trial 82WH49 is the final equilibrium strength. In contrast the P_{res} of trial 82WH49 in the year following a deep ripping operation is only 1 MPa at 19 cm depth. The differences between these two trials can be attributed to the higher amounts of fine particles at 84WH3. These would provide a significantly larger number of inter-granular connector assemblages and therefore would enhance any strength development processes, i.e. age hardening.

The data shown in Figure 1 together with other data from related trials (H. Daniel, unpublished data) indicate that the P_{res} of these soils after deep ripping and recompaction appears to increase exponentially with time, at least early on. On this basis, the following function is proposed to explain soil strength development with time after ripping and recompaction:

$$P_{res} = P_m - (P_m - P_i) \cdot e^{-\frac{t}{c}}$$

where P_{res} is the penetration resistance at time t, P_i is the initial penetration resistance immediately after a ripping operation at $t = 0$, P_m is the maximum penetration resistance to which P_{res} is converging with time, and the parameter c varies according to the initial state of soil compactness and has to be determined. The values of the parameters P_i, P_m and c for the fitted 82WH49 data ($r^2 = 0.97$***) are 0.5, 2.0 and 3.37, respectively.

In Figure 1 the equivalent typical strength level of adjacent uncleared bushland is also indicated. The virgin "loose" state is probably the result of very slow soil loosening processes involving soil fauna and flora. Under these conditions soil structure has sufficient time to stabilise and can resist overconsolidation by effective stresses and overburden pressures. Stresses introduced into the soil by disruption (land clearing operations) will render the soil in a state not able to support even the overburden and it will consolidate. The forces previously in equilibrium with the overburden pressure are reduced or diminished by disruptive forces, consequently the previous stable fabric can no longer be maintained.

Crop yield

Grain yields declined with time after ripping but always remained higher than for the unripped plots (Fig. 2). This is corroborated by the increase in hardpan strength with time after ripping as shown in Figure 1. Yield for the R84 treatment was systematically too low, indicating a less effective ripping operation, as treatments ripped two years before (R82) yielded significantly ($P<0.05$) more than UR in both seasons measured.

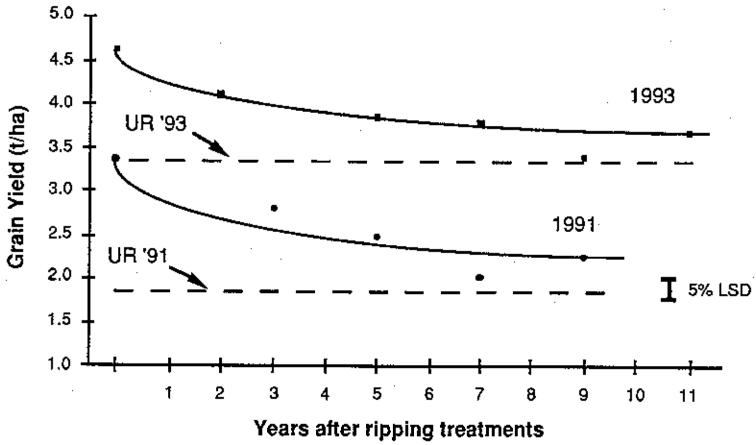

Fig. 2. Relationship of wheat yield with time after ripping for two different seasons at 82WH49.

Figure 2 shows that seasonal factors, predominantly rainfall distribution as well as rotation, have a much larger effect on yield than ripping history. The 1993 season out-yielded the 1991 season by 1.2 to 1.5 t/ha and followed a year of grass free lupins, compared with the 1991 crop following two years of pasture. Nevertheless, the long term yield advantages achieved, following a single ripping operation, demonstrate that controlled traffic systems have the potential to maintain a lower strength soil fabric on suitable soils. In the more common seasons with extended periods of high moisture stress when the hardpan strength is more critical for root growth, a lower strength fabric may result in greater benefits for the crop, i.e. the yield of R82 was 122% of that of UR in 1991 but was only 109% of that of UR in 1993.

CONCLUSIONS

The high porosities and the low stress levels found in virgin soils can generally not be maintained after taking these soils into agricultural production. The amount of energy transferred into the soils by the weight of agricultural machinery, increases stress levels and for many soils this results in a distinct zone with a high stress level.

Most of the soil resettlement appears to occur within the first year after soil loosening. The avoidance of wheel traffic, in particular during the first year after soil disruption, is essential to minimise the contribution of external loading to consolidation processes.

The success of any mechanical soil disturbance to achieve a lower stress state will greatly depend on the initial soil structure and how it was affected by various consolidation processes. Two soils can have the same fabric but different fabric stabilities. The latter will depend on the forces between soil particles and particle groups, if they are not the same each soil will probably exhibit different properties, e.g. strength-time relationships, stress-strain relationships etc.

ACKNOWLEDGMENTS

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NEGATING THE EFFECT OF TRAFFIC WITH IN-ROW SUBSOILING

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ABSTRACT

Extensive cone index measurements were used to evaluate the soil condition resulting from five years of a cotton (*Gossypium hirsutum L.*) - wheat (*Triticum aestivum L.*) double cropping experiment. Four cotton tillage systems including a conservation tillage practice of in-row subsoiling and planting into wheat residue stubble and two traffic systems were analyzed. The USDA-ARS Wide-Frame Tractive Vehicle (WFTV) was used to control traffic in the experimental plots. Contour graphs of cone index were used to determine differences in tillage and traffic systems. Traffic was found to reconsolidate soil that was initially completely disrupted to a 0.51-m depth into a soil condition similar to one that had never received a subsoiling treatment. Traffic was also found to decrease the total soil volume estimated for root growth using a 2 MPa limiting cone index value, but not the maximum rooting depth beneath the row, when an annual in-row subsoiling practice was used.

INTRODUCTION

Soil compaction plagues many parts of the world and affects many different crops. Here in the southeastern part of the United States, cotton has been found to be particularly susceptible to soil compaction [1]. Where soil compaction is a problem, subsoiling has been found to help alleviate it [2]. Subsoiling severely compacted soil provides increased rooting depth to withstand short-term drought conditions prevalent during the growing season in the southeastern United States. Soils in this region are subsoiled to a depth of between 0.3 m and 0.5 m on an annual basis. This is necessary because of wheel traffic and natural forces that cause this soil to reconsolidate. Identifying the major cause of soil compaction is difficult because of the interaction of these two phenomena.

The use of the Wide Frame Tractive Vehicle (WFTV) [3] at the NSDL allows experiments to be conducted to determine exactly how much random wheel traffic contributes to reconsolidation of soil disturbed by a subsoiler. This machine spans a 6-m growing zone that can then be kept completely free of wheel traffic unless a traffic treatment is specified. This vehicle operates on raised traffic paths and facilitates research to determine the effects of traffic and tillage on soil condition without confounding effects from nearby traffic.

MATERIALS AND METHODS

An experiment was conducted between 1987 and 1991 on coastal plains soils at the Alabama Agricultural Experiment Station, Auburn University, Agricultural Engineering Research Farm at Shorter, AL. The soil used was a Cahaba-Wickham-Bassfield sandy loam complex (Typic Hapludults) and contained a well-developed 0.08- to 0.15-m thick hardpan at a 0.2- to 0.3-m depth. Prior to starting the experiment, wheel traffic was run in a moldboard plow furrow incrementally across the field at a 0.2-m depth to reduce the natural variation in the depth and thickness of the hardpan.

A split-plot experiment using cotton and wheat as a double crop was designed with four replications. The main plots were a) conventional traffic and b) no traffic. The subplots contained various common cotton tillage systems[1] including: 1) complete surface tillage (disked and field cultivated) and annual in-row subsoiling to a 0.4-m depth and planting (D, FC, SS+P), 2) initial complete disruption of hardpan in 1987 (but with no annual subsoiling thereafter), complete surface tillage, and planting (CD, D, FC, P), 3) complete surface tillage, and planting (D, FC, P), and 4) in-row subsoiling to a 0.4-m depth (strip-tillage) with no surface tillage (SS+P). The initial complete disruption treatment (CD, D, FC, P) was accomplished by using a V-frame subsoiler on 0.25-m centers operating to a 0.51-m depth. A KMC[2] in-row subsoiler planter was used to plant cotton into the wheat stubble/residue in the strip-tillage treatment (SS+P) and to plant the annual subsoiling treatment. The same planter with the subsoilers removed was used to plant the remaining tillage systems.

The WFTV was used for all tillage treatments, even in plots that received traffic. All traffic treatments were applied with a John Deere 4440 or a high clearance sprayer. These machines would have been used had the WFTV not been available. All plots were eight rows in width and 4-row equipment was assumed to apply the correct traffic treatments. Recommended weed and insect control practices were used throughout the growing season for all plots. Cotton (McNair 220) was planted in 0.76-m rows at 220,000 seeds/hectare.

At the end of the five-year experiment, penetrometer readings were taken with an automatic recording penetrometer to determine changes in soil condition during this time. The penetrometer with base area of 130 mm^2 [4], and mounted on the WFTV was used to sample each subplot at five different locations. At each location, five penetrations were made, starting from the row middle on the untrafficked side of the row and moving in 0.19-m increments across the row and into the trafficked row middle (corresponds to traffic middle in treatments that received traffic). This sampling procedure allowed both tillage and traffic treatments to be analyzed. Four replications x 2 traffic main-plot treatments x 4 tillage subplot treatments x 5 locations within the subplots x 5 positions across each location were sampled to give a total of 800 penetrometer sets of force-

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[1]The tillage operations are defined by the following key: D (disk), FC (field cultivate), SS+P (subsoil and plant beneath row), CD (complete disruption in 1987), and P (plant).

[2]Use of a company name does not imply USDA approval or recommendation of the product or company to the exclusion of others which may be suitable.

distance data. Cone index data were taken at every 0.003 m depth down to an approximate maximum depth of 0.7 m.

The cone index data were averaged in depth increments of 0.05 m for all replications and locations using SAS software [5]. Contour graphs extending from the untrafficked row middle across the row to the trafficked row middle were then created from this data using SURFER contouring software [6]. These contour graphs show the potential root-impeding layers of compaction that are present in the soil profile.

RESULTS AND DISCUSSION

Comparison of contour graphs from the no-traffic plots (Figures 1, 2, 3, and 4) illustrate the beneficial effects of subsoiling. Only Figure 3 has had no subsoiling and the shallowness of the 1 MPa profile differs substantially from the other figures. Figures 1 and 4 also show the presence of the annual in-row subsoiler channel.

The contour graphs from the traffic plots (Figures 5, 6, 7, and 8) differ greatly from the contour graphs from no-traffic plots. In each graph, higher magnitude cone index profiles are much closer to the soil surface. An area of high soil compaction is noted beneath the surface in the trafficked row middle. Also, the in-row subsoiler slot is much easier to detect because of the soil recompaction near the slot.

An interesting comparison can be made between Figures 2 and 6 illustrating the effect of traffic on plots that were initially completely disrupted. A drastic change has occurred in these plots due only to the effect of traffic. The 1 MPa profile moved 0.2 m closer to the soil surface. The soil volume above this 1 MPa profile is near zero. Comparison of Figures 6 and 7 shows that the effect of the initial disruption in 1987 has almost disappeared and the soil condition is very similar to that tillage system that received no subsoiling treatment.

The effect of traffic on subsoiling in a conventional farming system can also be investigated by comparing Figures 1 and 5. The one major difference in these two figures is that the subsoil slot is much narrower in trafficked plots. The total volume of soil that is in a zone of minimal cone index is much greater in Figure 1, but the overall depth of the subsoil slot is almost the same. This result is also echoed by contrasting Figures 4 and 8, the conservation tillage system without and with traffic, respectively. The depth of the subsoil slot is greater in these latter two figures, but the trend is similar.

These contour graphs can also be used to estimate the soil volume available for proper root growth. According to Taylor and Gardner [7], a cone index of greater than 2 MPa can negatively affect crop yields. Figures 1-8 were each analyzed to determine the total soil volume that had a cone index greater than 2 MPa. The results are given in Figure 9. With the exception of the initial complete disruption system (CD, D, FC, P), traffic decreased the soil volume for root growth in each system. In the initial complete disruption tillage system, traffic negatively affected the soil volume between 1 and 2 MPa, but not above this limit. A significant difference is attributed to traffic in the SS+P tillage treatment. In this conservation tillage treatment, only a very small portion of the total soil volume had a cone index greater than 2 MPa in the untrafficked plots.

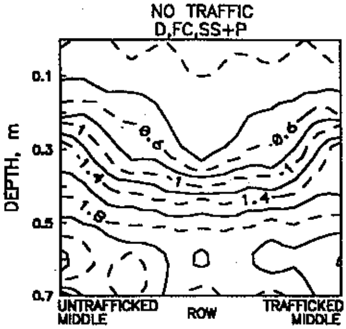

Figure 1. Cone Index Profiles (MPa) across the row for the disk, field cultivate, in-row subsoil and plant tillage treatment with no traffic.

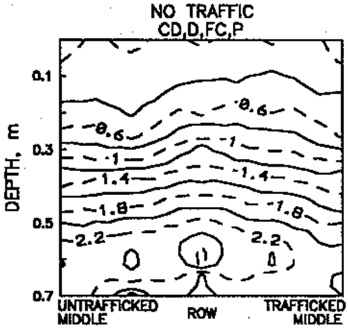

Figure 2. Cone Index Profiles (MPa) across the row for the initial complete disruption, disk, field cultivate and plant tillage treatment with no traffic.

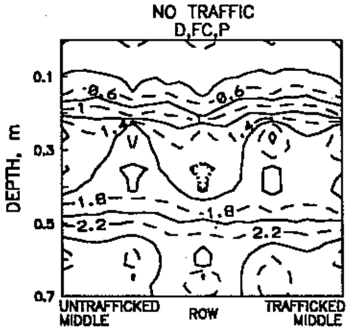

Figure 3. Cone Index Profiles (MPa) across the row for the disk, field cultivate, and plant tillage treatment with no traffic.

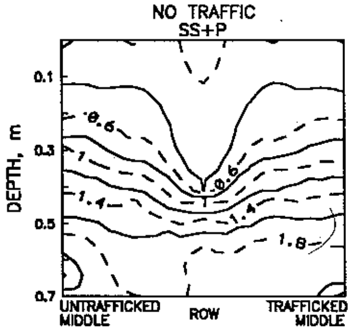

Figure 4. Cone Index Profiles (MPa) across the row for the in-row subsoil and plant tillage system with no traffic.

However, the amount of soil volume available to plant roots may not be as important as the overall soil depth available for rooting. Results reported by Raper et al. [8] showed that the conservation tillage practice of in-row subsoiling and planting (SS+P) had superior cotton yields in plots that received traffic as opposed to plots that received no traffic.

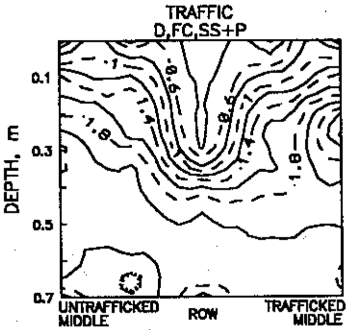

Figure 5. Cone Index Profiles (MPa) across the row for the disk, field cultivate, in-row subsoil and plant tillage system with traffic.

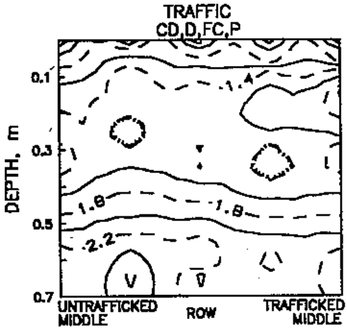

Figure 6. Cone Index Profiles (MPa) across the row for the initial complete disruption, disk, field cultivate and plant tillage system with traffic.

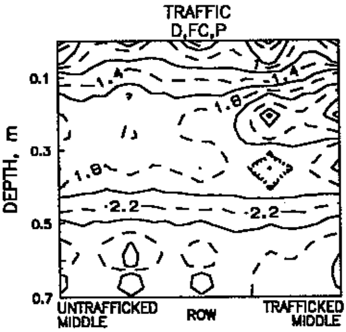

Figure 7. Cone Index Profiles (MPa) across the row for the disk, field cultivate and plant tillage system with traffic.

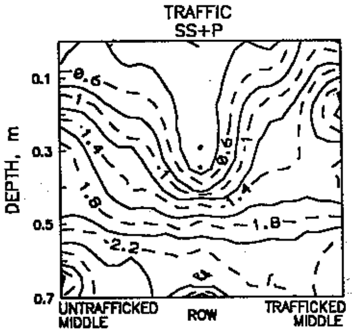

Figure 8. Cone Index Profiles (MPa) across the row for the in-row subsoil and plant tillage system with traffic.

CONCLUSIONS

1) Traffic caused soil in plots initially completely disrupted with a V-frame subsoiler in 1987 to reconsolidate into a state similar to soil in plots that had never been subsoiled.

2) Traffic alongside the row did not significantly change the hardpan depth beneath the row in plots that received subsoiling treatments.

3) The best soil condition resulted from the conservation tillage practice of in-row subsoiling and planting. This practice produced the lowest cone index, and the deepest depth to hardpan of any of the practices studied, even in trafficked plots.

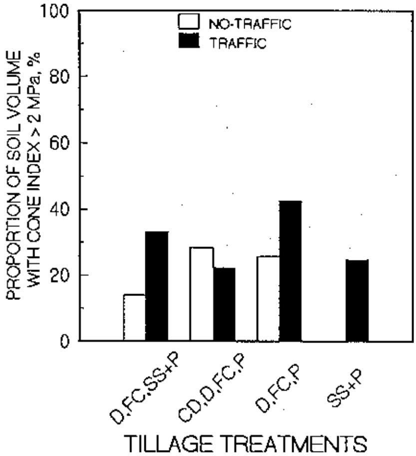

Figure 9. Effect of tillage and traffic treatments on the proportion of soil volume beneath row and wheeltracks with cone index greater than 2MPa.

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DETRIMENTAL EFFECTS OF CROPPING SYSTEMS ON SOIL QUALITY

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ABSTRACT

Current observations and measurements show, that intensification of crop production, by increasing the level of mechanization and by reducing of crop rotation, can be detrimental to the soil structure. As a result of this many fertile soil may undergo considerable physical degradation.

In this study we measured particle size analysis, particle density, bulk density, total and air-filled porosity, air permeability, shrinkage, tensile strength, compression characteristics, humus content, nutrients, reaction of soil, content of $CaCO_3$ in humus horizon of the forest-meadow chernozem from Pyrzyce Lowland (province of Szczecin, Poland). Soil cores were obtained from the field used for sugar beet (at the time before harvesting) at the depths: 0-30 (horizon A_P), 30-45 cm (horizon A_1).

The results indicate that there are not distinctive differences in chemical properties of the Ap and A_1 horizons. Considering soil physical physical conditions appreciable advantages were found for horizon A_1. This implies that root development in terms of soil physical conditions in horizon Ap might be hampered. Observed structural damages seems to be very persistent and difficult to be alleviated by usual tillage practices.

INTRODUCTION

Intensification of plant production, together with an increased level of mechanization and deviations from the principles of crop rotation, has the destructive effect on physical properties of soil. That is the reason of gradual degradation of fertile soil in many areas, which decreases its yielding ability. Such a disadvantageous situation has been noticed on the forest-meadow chernozem from Pyrzyce Lowland (province of Szczecin, Poland) [1], where density of clods formed during soil cultivation for wheat seeding has been within the range from 1,7 to 1,9 $g*cm^{-3}$. It has been supposed that one of the reasons of that excessive compaction might have been reduction of resistance to pressure, exerted to the uppermost layer of soil, caused by destruction of the soil natural structure. An attempt has been made to compare physical, mechanical and chemical properties of the soil at the Ap and A_1 layers in order to explain that phenomenon. The tests applied to samples drawn from sugar beet plantations just before the harvest.

MATERIAL AND METHODS

The research material has consisted of soil samples taken with metal cylinders of capacity of 100 cm^3 from the depth of 0-30 cm (Ap horizon) and from the layer 30 to 45cm deep (A_1 horizon). Field moisture and bulk density of those samples have been determined.

Having standarized moisture conditions at pF=10 kPa (on a gypsum plate) the following parameters have been determined: moisture, air content and air-permeability. Air-permeability of soil has been measured with the LPiR-1 apparatus, which is a standard equipment, used in metallurgical industry for determination of air-permeability of moulding sand . With this apparatus the pressure in space under the core sample, placed in holder, is measured and compared to provided constant air-pressure. The difference between those two pressures is a measure of air-permeability, expressed in $m^2*(Pa*s)^{-1}$.

Moreover disturbed soil samples have been taken into plastic bags and the following parameters have been determined: mechanical composition (Bouyoucos-Casagrande's method modified by Prószynski), humus content (Tiurin's method), soil reaction (electrometric method), hydrolytic acidity (Kappen's method), sum of exchangeable cations (Pallman's method), liquid limit (Cassagrande's apparatus) and limit of plasticity (by rolling), soil compactability in uni-axial compression test and tensile stregnth (Brasilian test).

The soil used in compactability test was air dried to a moisture content at which it was easy to crumble. Only the soil fraction with particles size less than 8 mm and larger than 0.6 mm was used in the test. Prior to the test the soil moisture has been stabilized at the value of pF=10 kPa. The samples have been deformed in a consolidometer with pressure increasing gradually from 50 to 300 kPa. In test, four incremental static loads of 0,05; 0,1; 0,2; and 0.3 MPa were applied to the soil, allowing air to escape freely from the sample cylinder. Loading stresses were relieved between succesive pressure levels.

In tensile stregnth tests the samples compacted in the consolidometer have been used, having been dried earlier at the temperature of 105 ^{o}C. In this test the crushing force F was applied to the soil core, which was placed on its side between two horizontal plates. The tensile strength was calculated through the formula

$$R=2*F*(PI*D*L)^{-1}$$

where D and L are the sample diameter and length, respectively.

RESULTS AND DISCUSSION

Visually the A_1 horizon differs both in colour and in structure from the Ap horizon.

Percentage of mechanical fractions (Table .1) in the Ap horizon corresponds to silty heavy loam and in the A_1 horizon - to heavy loam (in accordance with standards of the Polish Pedological Association).

Table 1

Mechanical composition of soil in horizons Ap and A_1

Hori-zon	Particle size in mm						
	>1	1-0,1	0,1-0,05	0,05-0,02	0,02-0,005	0,005-0,002	<0,002
	%	% particle size <1 mm					
Ap	0,4	20	15	13	19	18	15
A_1	0,1	14	16	6	13	20	31

During tests of physical properties of soil (Table 2) compaction at the Ap horizon was proved to exceed optimum values. In previous studies it has been shown, that the upper limit of optimum bulk density for light silty loam with humus content of 1.8% range between 1.41 and 1,46 $g*cm^{-3}$ [2].

At Ap horizon considerable decrease of air-filled porosity has occured. According to earlier findings. for most plants it should be in the range of 10 to 15% and 15 to 20% for sugar beets. Favourable, to requirements of plants, air-filled porosity of 14,1 % has sustained at the A_1 horizon.

Table 2

Physical properties of soil determined in the field

Horizon	Mass water contens	Soil density	Total porosity	Air-filled porosity
	[% w/w]	[g*cm^{-3}]	[%]	[%]
A_P	16,0	1,66	32,8	6,2
A_1	19,4	1,44	42,2	14,1

Physical soil properties, determined at pF 2 (Table 3) prove that soil at horizon A_1 has higher field water capacity and higher non-capillary porosity than soil in the horizon Ap.

Air-permeability is the property, which makes the difference between Ap and A_1 horizons the most clear. Heigh soil density in the Ap horizon, together with its very low air-permeability, suggest, that majority of the large pores might have been destroyed.

From the values of determined plasticity limits the conclusion may be drawn, that physical readiness for cultivation of the soil in the whole humus horizon (Ap and A_1) is reached at similar moisture. Plasticity indexes prove that A_1 horizon soil consists of more clay particles smaller than 0,002mm. It has been confirmed by particle size analysis (Table 1). There is possibility, that some fine particles bave been moved downwards during water infiltration. The consistency limits determined indicate that the soil in Ap horizon is susceptible to surface run off and erosion.

Table 3

Physical properties of soil determined at pF=2 and Atterberg limits

Horizon	Mass water content	Air porosity	Air permeability	Limit of liquid	Limit of plasticity	Plasticicity index
	at pF=2					
	[% w/w]	[%]	[m^2/Pa*s]	[% w/w]		
A_P	21,5	1,1	3,4*10^{-8}	37,5	25,0	12,5
A_1	26,7	7,8	91,5*10^{-8}	47,7	24,9	22,8

Data presented in Table 4 indicate, that the soil tested is rich in humus, and that its reaction is optimum for most cultivated plants.

Table 4

Humus content, content of $CaCO_3$ and reaction of soil in horizons A_P and A_1

Horizon	Humus content [%]	pH_{H_2O}	pH_{KCL}	Content of $CaCO_3$ [%]
A_P	3,44	7,9	7,2	1,4
A_1	3,64	6,9	6,4	0,16

Results shown in Table 5 point out that bumus borizon has high sorptive capacity with a very high degree of base cation saturation.

Table 5

Sorptive properties of soil in horizons Ap and A_1

Horizon	Hydrolitic acidity H_h	Exchangeable cations					Sorption hydrolytic capacity T	Sorption degree with basic cations V
		Ca^{2+}	Mg^{2+}	K^{2+}	Na^{2+}	Sum of cations S		
	me/100 g							[%]
Ap	0,98	21,58	1,99	0,97	0,28	24,82	25,80	96,2
A_1	1,28	20,99	2,59	0,55	0,36	24,49	25,77	95,1

Relatively high humus content and advantageous mechanical composition at the Ap and A_1 horizons are features of soil, which may be able to persist stable structure in the whole humus horizon.

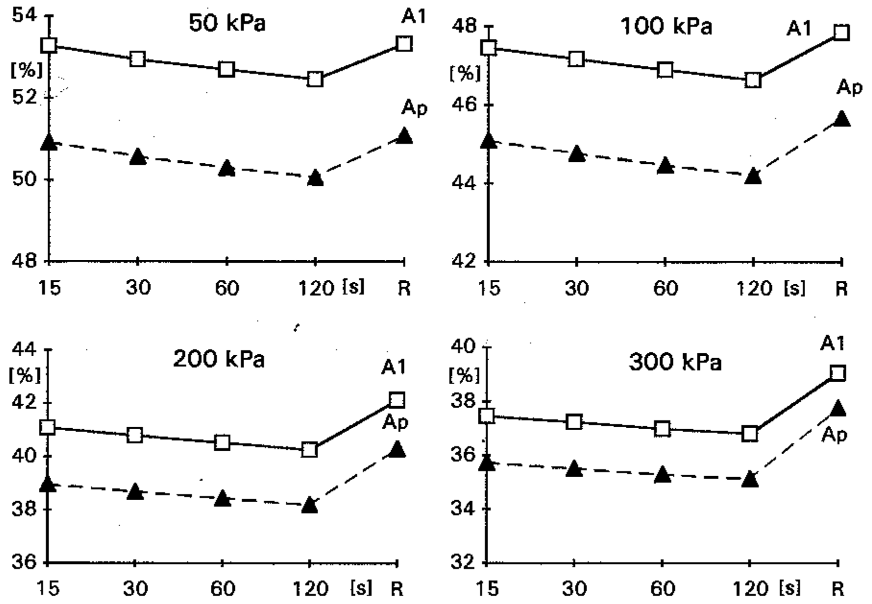

Fig. 1. Changes of porosity in dependence of deformation time and exerted pressure: R - porosity after rebounding

However the results of the uni-axial compression tests have shown, that the structure of both soil horizons may be different. When comparing the porosities of compressed samples it can be seen, that the soil from Ap horizon was more compacted in the whole range of applied load than the soil from the A_1 layer (Fig.1). From tensile strength tests it has also been found out, that in the Ap layer, sample tensile stregnth has been about 50% lower than in the A_1 layer (209 and 328 kPa respectively). It means, that particle bounds in the former case are weaker than in the later one.

The results of those two test, compactibility test and tensile stregnth test, are related to the present state of soil structure in both studied horizons. Since there have been no substantial differences noticed in other properties of the soil layers tested, the structural changes may be recognized to be the main reason of the reduced compaction resistance of the Ap layer. It means, that improper physical state of soil at the Ap horizon has been mainly caused by negative influence of external factors, such as soil compactive actions of agricultural machines and vehicles.

Cultivation systems, used up to the present, base on intensive simplified crop rotation with wheat, beets, wheat, rape, wheat and beets grown in succession. There is no enough care taken to reduce the intensity of compactive efforts exerted by agricultural machinery. A change of technology of plant growing may be one of the methods of improvement of the physical properties of the Ap layer in that soil.

CONCLUSIONS

1. The basic reason of the physical degradation of studied soil is its low compaction resistance in the Ap layer.
2. Continuation of the current agrotechnic procedures will result in the further degradation of soil physical properties in this agricultural area.
3. To improve the physical state of the soil tested the change of the technology of crop production is recomended. The number of passages of vehicles and machines should be reduced. The possible improvement of properties of the soil has to be preserved by appropriate crop rotation and organic fertilization.

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MANAGEMENT HISTORY AND STABILITY UNDER RAIN OF A HARDSETTING ALFISOL IN THE SEMI-ARID TROPICS

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ABSTRACT

Hardsetting soils have inherently weak structural stability when wet. Raindrop impact collapses structure and leads to surface sealing, increased runoff and erosion. To ensure sustainability of agriculture on these soils, management practices that strengthen inherent soil structural stability are needed. Tillage-based systems, because they reduce soil organic matter content, are unlikely to be sustainable in the long-term. Possible alternatives are to use organic mulches or to introduce ley pasture rotational systems in which tillage is avoided for a number of years. Alternative management options are being tested in a field experiment that was started at ICRISAT in India in 1988 to study effects on runoff and erosion and on crop yield. In this experiment, annual crops (sorghum, millet or maize) are grown using combinations of tillage depths (0, 10, and 20 cm) and organic mulches (no mulch, rice straw @ 5 t/ha, and farmyard manure @ 15 t/ha); also, perennial species (*Cenchrus ciliaris, Stylosanthes hamata* and *Cajanus cajan*) are grown without any tillage (Smith *et al.* Soil and Tillage Research 25:195-215, 1992).

After the treatments had been in place for four years (1992) a series of tests was carried out in sub-plots using simulated rain to compare the effect of particular treatment histories on soil stability under rain. The effect of tillage superimposed on the treatment histories was studied by carrying out tests both before and after tillage. The tests before tillage showed the cumulative effect of treatment histories through changes in void structure, soil strength and soil cover present at the time. Tests after tillage showed the degree of persistence of cumulative effects of treatments on inherent resistance to surface sealing and compared this with the effect of soil cover.

Results show that although undisturbed soils in some of the treatments have increased stability, as indicated by higher infiltration rate, after tillage there is no worthwhile difference between treatments. Surface cover has a major effect regardless of past management history. It is concluded that, although reduced tillage systems improved infiltration on this hardsetting soil, four years is not long enough under any of the treatments to achieve an increase in the soil's inherently low resistance to aggregate breakdown and surface sealing under raindrop impact. To maximise the residual beneficial soil structural effects of the ley pasture for subsequent crops, soil management practices should maximise soil cover and minimise the degree of soil disturbance.

INTRODUCTION

Hardsetting soils (1) have inherently weak structural stability when wet. Raindrop impact, or in some cases simply wetting the soil, causes soil structure to collapse and leads to surface sealing, increased runoff and erosion. Runoff is undesirable because these soils often occur in semi-arid regions where water availability is a major factor limiting crop yield. Erosion is undesirable because the soils are often shallow. As hardsetting soils dry, soil strength increases rapidly and root penetration is restricted. Farmers commonly rely on tillage to manipulate soil structure to assist water entry and root penetration. Tillage is difficult to manage because there is a limited 'window of time' when soil moisture conditions are suitable. These difficulties are compounded for resource-poor farmers who have limited tillage equipment and power sources available. It is usual to till the soil as soon as it is softened by rain. However, if heavy rains cause runoff on freshly tilled soil, rates of soil erosion can be very high. Also, tillage can destroy existing macropores structure, compact underlying soil and, over a long period, tillage-based farming systems may reduce soil organic matter content.

Thus, tillage-based systems on these soils are unlikely to be sustainable in the long-term. To ensure sustainability of agriculture on these soils, management practices should foster creation of a suitable pore size distribution (to increase infiltration) and strengthen wet soil stability so that the pore structure is stable (to maintain infiltration and resist erosion when runoff occurs). Possible alternatives are to use organic mulches or to introduce ley pasture rotational systems in which tillage is avoided for a number of years. This approach has been successfully used in the humid tropics (2), but biological agents may be less effective in the drier climate of semi-arid regions (3). However, during the rainy season the moisture regime is favourable, and biological factors may be able to be exploited at the time when it is most important to influence physical and crop growth processes.

MATERIALS AND METHODS

The Soil

Alternative management options are being tested in a field experiment which was started at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) at Hyderabad, India in 1988 (4). The soil belongs to the Patancheru series which is a member of the clayey-skeletal, mixed, isohyperthermic family of Udic Rhodustalfs (5). It is locally regarded as a crusting, profile-hardening soil. The textural profile consists of a sandy loam merging to sandy clay loam or light clay at 10-15 cm and then to gravelly sandy loam overlying murrum (parent material) rich in quartz gravel at depths ranging from 30-70 cm. It is formed on weathered granite-gneiss.

The Experiment

Runoff and erosion are measured using collection troughs and tipping buckets. Annual crops (sorghum, millet or maize) are grown using combinations of tillage depths: 0 (T_0), 10 (T_{10}), and 20 cm (T_{20}) and organic mulches: no mulch (N_m), rice straw @ 5 t/ha (R_m), and farmyard manure @ 15 t/ha (F_m). The tillage (with duckfeet tines) was performed just before sowing and there was no secondary tillage apart from the disturbance associated with sowing and hand weeding. The mulch treatments were applied within 10 days after sowing, as surface cover between the rows of emerging seedlings in the tillage treatments.

Also, perennial species (*Cenchrus ciliaris, Stylosanthes hamata* and *Cajanus cajan*) are grown alone and in combination, without any annual tillage or mulches. There are three replications. Plot size is 28 m by 5 m and the slope is approx. 2 %.

Tests using Simulated Rain
After the treatments had been in place for four years (1992) a series of tests was carried out in sub-plots of selected treatments using simulated rain to compare the effect of particular treatment histories on soil stability under rain. The effect of tillage superimposed on the treatment histories was studied by carrying out tests both before and within a few days after hand tillage. Tests were also carried out on a nearby soil that had been under natural regrowth grasses for at least 15 years. The tests before tillage showed the cumulative effect of treatment histories through changes in void structure, soil strength and soil cover. Tests after tillage showed if any cumulative effects on resistance to surface sealing persisted and compared them with the effect of soil cover.

A rotating disc rainfall simulator was used on plots of approx. 1 m^2. Rainfall simulator sub-plot walls were heavily weighted and forced into the soil with minimum disturbance. Runoff rate was calculated from the time to fill a container of known volume. Rainfall rate was measured by collecting all water falling on the plot with a metal pan at the end of each run. Infiltration rate was calculated by subtracting runoff rate from rainfall rate. For comparative purposes, because the rainfall rate of approx. 80 mm/h varied slightly between each run, infiltration rate was normalised across all runs by expressing it as a percentage of the rainfall rate. Data from selected plots are presented.

Sediment concentration was measured in samples of runoff water, and the 0-3 mm layer was sampled after each run for measurement of water stable particle size distribution. by wet sieving. Loch (7) found that the % soil particles (primary particles and aggregates) <0.125 mm in size in the surface crust produced by rainfall was related via an exponential decay function to the final infiltration rate. The wet samples were separated into size fractions: >2.0, 2.0-0.5, 0.5-0.25, 0.25-0.125, and <0.125 mm.

RESULTS AND DISCUSSION

Infiltration on undisturbed soil as found at the end of the dry season
Sub-plots were tested in an 'as found' condition; cover was not removed.

The effect of 4 years of annual tillage, mulches and applied cover
From Figure 1(a) it appears that runoff occurs within 10 mm of rainfall on all treatments. This shows that a seal is present or forms quickly under raindrop impact. Sealing may be slightly slower on $T_{10}R_m$ and $T_{10}F_m$ treatments and infiltration rate falls more slowly on T_0R_m and T_0F_m treatments. The final infiltration rates for T_0N_m, $T_{10}N_m$ and $T_{10}F_m$ treatments form a group <10 mm/h whereas T_0F_m, $T_{10}R_m$ and T_0R_m treatments form a group with final rates of approx. 20 mm/h. Surface cover was 5-10 % in N_m and F_m treatments and 20-30 % in R_m treatments. Surface sealing appears relatively unaffected by the cover from remnants of the rice mulch applied in the previous season. This may be because the straw remains as small fragments and is easily moved around by heavy rain. However, with the exception of $T_{10}F_m$, there is evidence that residual effects of mulch maintain higher final infiltration rates.

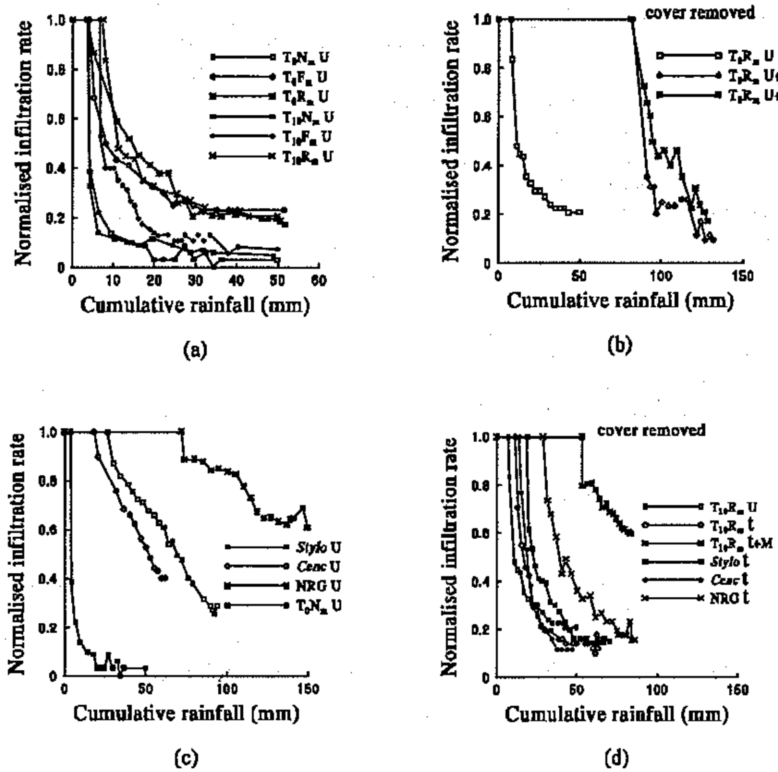

Figure 1. The effect of history on infiltration into an Alfisol at ICRISAT. (a) Effect of 4 years of annual tillage and mulch on undisturbed soil. (b) Effect of added rice straw or mesh cover on undisturbed soil. (c) Effect of 4 years of perennials and natural regrowth grasses on undisturbed soil. (d) Residual effect of management history after recent tillage. (U = Undisturbed; NRG = Natural Regrowth Grasses; S = rice straw; M = mesh; t = recently tilled; *Cenc* = *Cenchrus*)

From Figure 1(b), if cover is applied either in the form of rice straw (5 t/ha) or an insect mesh suspended 1-2 cm above the soil surface, infiltration rate remains at the potential rate. When the cover is removed, runoff is immediate and infiltration falls rapidly. This suggests that there was not a pre-existing surface seal present on the undisturbed soil when the tests were carried out. Thus the fall in infiltration shown in Figure 1(a) appears due to a fresh seal being formed. The high infiltration rate when the surface is protected is considered to be due to water entering macropores created by soil fauna; such pores are visible in all treatments, not just the mulch treatments.

The effect of 4 years of undisturbed perennial species

Cover levels were higher on *Cenchrus* (50 % as tussocks interspersed with bare areas) and *Stylo* (70-80 % evenly distributed) treatments and on the nearby soil under natural regrowth grasses (NRG; 90 %). From Figure 1(c) it appears that *Cenchrus* and *Stylo* have similar behaviour. Rainfall infiltrated before runoff occurs is higher and the rate of fall of infiltration rate is slower than for the undisturbed tilled soils in Figure 1(a). T_0N^m is included in Figure 1(c) for comparison. NRG showed highest infiltration before runoff and slowest rate of decline. It appears that pores that conduct water into the subsoil, and are protected by cover, are critical for infiltration. Faunal pores existed in all treatments.

Infiltration on recently tilled soil

The effect of 4 years of annual tillage, mulches, perennials and applied cover

Figure 1(d) shows that the rainfall infiltrated before ponding and runoff is slightly higher for the perennials (*Cenchrus* and *Stylo*) and higher again for NRG. Where mesh cover is present, infiltration before runoff is much higher again. Surface roughness was similar and the differences are considered to reflect the soil's ability to withstand surface sealing under raindrop impact. Clearly the residual effect of 4 years of perennials has been only marginal and is rather less than the resistance on natural regrowth grassland. The result under mesh shows the need for cover if soils are tilled at the start of the rainy season.

Effects on aggregate stability under rainfall

Are there stable aggregates present in undisturbed soil?

Yes. Wet sieving after gentle wetting of samples taken from the T_0N_m soil showed that 13 % of material was <0.125 mm; the same soil after puddling by hand (to destroy aggregates) had 24 % material <0.125 mm. This shows there are some stable aggregates present. However, when samples were taken from the surface of undisturbed soil after rain the % material <0.125 mm (meaned across all plots) was 18.4 %. It appears that the rate of wetting associated with rainfall or raindrop impact has caused aggregate breakdown.

Do stable aggregates persist after rain on recently tilled soil?

No. Wet sieving of samples taken from the $T_{10}N_m$ soil showed % material <0.125 mm ranged from 24-27 % compared with 23-28 % in the same soil after puddling. Sampling the top cm of soil in three layers showed that this level persisted to a depth of 10 mm. This suggests that either aggregates breakdown upon wetting to saturation or the effects of raindrop impact extend to a depth of 10 mm. This shows that there is no thin seal on the soil surface; it may reflect structure collapse upon fast wetting of the tilled layer.

Does soil cover affect aggregate breakdown in recently tilled soil?

Yes, but the effects are slight. The mean for samples taken after rain on mesh covered recently tilled soil was 19.7 %. This was significantly ($P<0.05$) lower than the mean value of 22.5 % found after rain on uncovered freshly tilled soil. Although the means are significantly different, this difference is unlikely to account for the large difference in infiltration characteristics found for covered and uncovered recently tilled soil (see Figure 1(b) and (d)).

The surface sealing mechanism

Loch (7) found that infiltration rates <10 mm/h, as found in this study, were usually associated with >40 % aggregates <0.125 mm. His equation would over-predict infiltration rate for this soil as levels of material <0.125 mm were approximately 25 %. Sealing appears to be not due to aggregate breakdown, which happens on soils protected by mesh, which retain high infiltration rates, but rather to rearrangement or compaction of particles and aggregates in the surface layer. The concentration of sediment in runoff was significantly ($P<0.05$) higher in uncovered recently tilled soil than on mesh covered soil (4.0 vs 1.9 kg/m^3). Recent tillage appears to weaken aggregates by shearing and makes fine material more easily detached by raindrops. Soil under cover had significantly more aggregates >2 mm.

CONCLUSION

There are water conducting macropores in undisturbed soil in all treatments at the end of the dry season. In the absence of surface cover, surface seals form within a few minutes or mm of rain. Aggregates breakdown due to rainfall wetting but it is sorting and consolidation of the soil surface rather than aggregate breakdown, that causes surface sealing. Tillage destroys stable macropores and weakens aggregates by shearing thus making fine sediment more easily detached, entrained and eroded. Four years of perennials is not long enough to produce residual effects that will resist surface sealing after tillage. Management practices should maintain cover and reduce disturbance to enhance infiltration and reduce erosion at the start of the rainy season.

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CROP RESIDUE EFFECTS ON SOIL COMPACTION

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ABSTRACT

A field experiment was conducted to quantify the effects of rye cover crop components on machine-induced soil compaction. Four ground cover regimes - live rye, chemically-desiccated rye, rye with above-ground biomass removed, and bare soil - served as treatments. Single- and multipass effects of machine traffic on dry bulk density, pore size distribution, and saturated hydraulic conductivity were defined by laboratory analysis of undisturbed soil cores. Treatments that included a rye cover produced samples with significantly lower dry bulk densities and higher noncapillary porosities than the bare soil treatment for the soil surface layer ($\leq$ 7.5 cm).

INTRODUCTION

Surface residues have been shown to reduce effects of machine-induced soil compaction in agricultural and forestry situations. Bulk density differences caused by logging traffic on skid trails protected by decaying vegetative matter were shown to be less than half those observed on major trails that had been stripped of organic cover (1). Corn residues were shown to act as a cushion, reducing stress measured 20 cm below the center of a tractor wheel track in a soil bin experiment conducted on a silt loam (2). However, the reduction in stress was not large enough to cause "any great change" in the soil matrix-water-air relationship due to a single tractor pass.

Plant roots alter soil response to applied loads. The presence of roots in soil tested in a direct shear device was shown to cause a widening of the shear zone, requiring each soil particle to move less than with a narrow shear zone (3). Although there is no accepted approach to relating soil shear strength to soil compaction (4), the idea of force redistribution provides a sense of the mechanism by which roots could increase soil compaction resistance.

A field research project, supported by laboratory studies, was undertaken to investigate surface residue cushioning and root reinforcement effects on machine-induced soil compaction with the following objectives: 1) Evaluate the effects of above-ground rye residue condition - live versus desiccated - on machine-induced soil compaction; 2) Separate root reinforcement effects from surface residue cushioning effects by including a residue-removed treatment; and 3) Investigate cover-soil type interaction effects on machine-induced soil compaction.

MATERIALS AND METHODS

Experimental Design

The experiment, conducted at two locations on the Virginia Tech Whitethorne Research Farm was begun in October, 1992. Each location provided consistent soil type (Table 1) and slope. Rye (*Secale cereale*) was planted on an upland site in a Zoar loam (2 - 7% slope) and on a terrace adjacent to the New River in a McGary silt loam (0 - 2% slope).

Table 1 Soil texture, compactibility, liquid and plastic limit data for the Ap horizon.

Property	Soil Type	
	Zoar Loam	McGary Silt Loam
Maximum Dry Density (g/cm^3)	1.76	1.67
Optimum Moisture Content (%)	16.1	19.6
Plastic Limit (%)	20.9	25.0
Liquid Limit (%)	24.9	30.3
Texture (Sand/Silt/Clay %)	38.1/49.5/12.4	33.9/46.9/19.2
Ap Horizon Depth (cm)	25	28

A generalized, randomized complete block experimental design, which allows investigation of block-treatment interaction, was used to investigate the effects of cover crop components on machine-induced soil compaction. Soil type provided the blocking factor for the compaction study. Four ground cover treatments were included in each block: 1) Fallow - bare soil; 2) Rye -above-ground biomass removed; 3) Rye - chemically desiccated; and 4) Rye - live crop. The fallow treatment was included as an experimental control. Inclusion of the rye treatment with above-ground biomass removed was intended to reveal the contribution of undisturbed plant roots to soil strength. Potential mitigation of soil compaction effects by two treatments in which above-ground biomass is maintained was also examined. One, chemical desiccation of a standing cover crop, is practiced by farmers using no-tillage crop production methods. The other, involving mechanical manipulation of, and tracking upon, a growing cover crop, is reflective of a new set of sustainable farming practices under development at Virginia Tech (5). Four treatment replicates were present in each block. Effects of three levels of machine traffic were examined: one, three, and five tractor passes. Within each treatment replicate, two sets of soil core samples were taken from each traffic zone. Four sets of soil core samples were taken from uncompacted zones to establish initial conditions.

All plots were initially tilled with a parabolic ripper to a mean depth of 29 cm. Fertilizer was applied according to soil test recommendations, then all plots were disked three times with an offset disk before rain halted field work. The plots were disked for a final time after soil moisture conditions returned to favorable levels. Rye was planted on all cover-cropped plots on November 11 in 18-cm rows at a rate of 101 kg/ha.

Rye biomass samples were taken from each cover-cropped plot at locations adjacent to soil core sampling sites. Desiccated plots were treated with paraquat mixed with a surfactant on May 16, 1993. All above-ground rye biomass was cut and removed by hand from residue-removed plots over the May 21-24 period.

The soil in the plots was loaded by passage of a 5 901-kg Case-International Model 1594, two-wheel drive tractor equipped with six front-mounted, cast-iron weights and rear tires partially filled with liquid ballast. Additional ballast was provided by a mounted implement that was carried by the tractor lift system. Ballast was arranged to achieve a static weight distribution of approximately 20% on the front axle and 80% on the rear axle. Tire inflation pressures were set at levels recommended by the tractor manufacturer for general field work conditions. All plots were tracked at 4 km/h at one time to ensure soil moisture content consistency across each level of machine passes. Sets of wheel tracks for different traffic levels were separated by a distance of approximately 2.4 m to prevent any contamination of intertrack, undisturbed soil samples by wheel track compaction.

Loose soil samples were collected from core sampling sites immediately after tracking to provide gravimetric moisture content data. Undisturbed core samples collected at two depths during the period June 1-10 provided the basis for bulk density, pore size distribution, and hydraulic conductivity testing. One cylindrical core, 5 cm in diameter and 5 cm in length, taken from 2.5 to 7.5 cm depth zone, represented surface compaction effects. Another core, taken from the same sampling site from the 15 to 20 cm depth zone, represented effects from well into the primary tillage zone.

Laboratory Analysis

Physical and cbemical property data were determined for the soil types. Standard Proctor compaction testing results were used to develop a moisture content-dry density curve for each soil type (6). Since the pattern of real compaction under tire loads has been found to compare well with the standard Proctor compaction test (7), test results were used to aid interpretation of field experiment results.

Saturated hydraulic conductivity values for intact soil core samples were determined by using the constant head method with a 25-cm column of water (8). A tension table apparatus (9) was used to determine capillary and noncapillary porosity by evacuating soil macropores (≥ 0.06 mm in diameter) with a 50-cm water column which created a potential of -4.9 kPa. Soil samples, weighed after reaching equilibrium on the tension table, were oven dried at 105°C to a constant weight to determine dry bulk density (10).

RESULTS AND DISCUSSION

Soil samples from the surface layer provided clearer evidence of machine-induced compaction effects than samples from the 15 to 20 cm depth zone. Therefore, all results presented in this paper pertain only to soil from the 2.5 to 7.5 cm depth zone. Treatments affected the potential covariates, soil moisture content and initial bulk density (Tables 2 and 3). As a result, analyses of covariance were not performed since moisture content and initial bulk density effects were statistically inseparable from treatment effects.

Table 2 Surface layer soil moisture content means for each soil type and each treatment (%).

	Soil Type	
Treatment	Zoar loam	McGary silt loam
Fallow	16.0	18.0
Live Crop	12.1	16.6
Desiccated	14.8	18.8
Residue Removed	13.0	16.2

All cover cropped treatments had initial bulk densities that were higher than that of the fallow treatment. The desiccated treatment was not statistically different from the fallow treatment. After one traffic pass, the fallow treatment was compacted to a higher level than any cover-cropped treatment; after five passes, the fallow treatment had a significantly higher bulk density mean than any cover-cropped treatment (Table 3).

Table 3 Bulk density means pooled across blocks (g/cm^3).

Treatment	Number of Traffic Passes 0	1	3	5
Fallow	1.232 b*	1.372 a	1.442 a	1.457 a
Live Crop	1.290 ab	1.356 a	1.401 ab	1.412 b
Desiccated	1.245 b	1.333 a	1.375 b	1.407 b
Residue Removed	1.313 a	1.344 a	1.365 b	1.396 b

* Means within a column followed by the same letter are not significantly different using Fisher's F-protected LSD, $\alpha = 0.10$.

Total soil porosity is calculated directly from bulk density; treatments that increase bulk density decrease total soil porosity. Measurement of total porosity is of limited value, however. Pore size distribution, the measure of capillary and noncapillary pore volumes, provides much more insight into soil air and water holding and transmission characteristics.

Initial capillary porosity means were affected by the treatments. Live crop and residue removed treatment means were significantly higher initially than fallow and desiccated treatment means. The treatment means, statistically equivalent following one traffic pass, remained so following three and five traffic passes. Although means for each treatment increased with each traffic pass, soil pore space disruption effects due to traffic were more clearly seen in the noncapillary porosity data.

The treatments affected initial noncapillary porosity means. Desiccated and fallow treatment means were greater than those of the live crop and residue removed treatments. Once again, one machine pass led to statistical equality among all treatment means. However, soil particle rearrangement resulting from further traffic caused reductions in noncapillary porosity and significant differences between cover-cropped and fallow treatment means (Table 4).

Table 4 Noncapillary porosity means pooled across blocks (%).

Treatment	Number of Traffic Passes 0	1	3	5
Fallow	24.36 a*	14.95 a	11.64 b	10.36 b
Live Crop	19.34 b	16.24 a	12.75 b	12.33 a
Desiccated	22.94 a	17.13 a	13.88 ab	12.25 a
Residue Removed	18.83 b	16.45 a	15.67 a	13.85 a

* Means within a column followed by the same letter are not significantly different using Fisher's F-protected LSD, $\alpha = 0.10$.

Noncapillary porosity is also referred to as aeration porosity. Soil aeration is likely to become limiting to plant growth when the air-filled porosity falls below about ten percent (11). The noncapillary porosity mean for the fallow treatment was driven to ten percent by five machine passes. Cover-cropped treatment means were 18 to 34 percent higher than the fallow mean after five machine passes.

Saturated hydraulic conductivity is strongly affected by soil porosity. Saturated hydraulic conductivity values exhibited a strong relationship to corresponding noncapillary porosity values raised to the fourth power. All treatments exhibited very rapid hydraulic conductivity initially (Table 5), but five machine passes reduced the conductivity of the fallow treatment to a moderate level while cover-cropped treatment means remained in the moderately rapid to rapid range (12).

Table 5 Saturated hydraulic conductivity means pooled across blocks (cm/h).

Treatment	Number of Traffic Passes			
	0	1	3	5
Fallow	76.0	22.2	2.0	1.5
Live Crop	38.5	15.8	4.9	4.1
Desiccated	86.1	24.3	8.3	5.4
Reside Removed	34.8	15.1	9.1	6.5

* Means were not significantly different based on Friedman Block/Treatment Test results.

Live crop and desiccated plots produced rye dry matter yields ranging from 2.3 to 8.7 t/ha. The hypothesized relationship between crop yield and soil response to machine traffic did not result due to interaction between crop yield and soil moisture (13).

CONCLUSIONS

Based on field research results, the following statements can be made: 1) Cover cropping cultural practices affect soil properties that can impact primary crop performance; 2) Cover crop components - roots and above ground biomass - each contribute to the attenuation of machine-induced soil compaction; 3) Multiple machine passes produce statistically significant differences between cover-cropped and fallow treatments in regard to soil bulk density and noncapillary porosity; 4) The condition of above-ground rye biomass affects soil moisture conditions and the resultant effects of machine traffic; and 5) No evidence of cover-soil type interaction was discovered for the treatment combinations examined in this project.

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EFFECT OF PREPLANT SOIL TILLAGE IN MAIZE MONOCULTURE ON SOIL PHYSICAL PROPERTIES

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ABSTRACT

The effect of different preplant tillage methods on soil physical properties was investigated on an alluvial soil.

INTRODUCTION

A diverse response of the soil to seedbed preparation has been found in the investigations made to date (1, 2, 3, 4). The aim of this field study was to find out to what degree seedbed preparation for maize grown under monoculture can optimise soil physical properties. A possibility to apply a simplified (0-tillage) system for maize production was investigated.

MATERIAL AND METHODS

The experiment was run in the years 1991 - 1993 on an alluvial soil . The design was two-factorial equivalent sub blocks in four replications.

The layout was as follows:
Factor 1: a) no mulching
b) straw mulch applied
Factor 2: a) conventional tillage (ploughing + cultivation)
b) simplified tillage (disking)
c) no tillage

The measurements of soil physical properties (soil density, moisture content and temperature) were made at 0-5 and 25-30 cm depths on three dates during maize growth.

Soil density and moisture content were measured using 250 cm^3 cylinders. Soil temperature records were taken with an electronic Thera thermometer.

RESULTS AND DISCUSSION

The effect of three preplant tillage methods involving application of straw mulch and no mulching on soil physical properties is presented in Table 1.

The study showed soil density, gravimetric moisture content and temperature to vary with the tillage methods used.

Table 1 Soil physical properties as affected by different preplant tillage treatments

Tillage treatment	Soil bulk density ($Mg \cdot m^{-3}$)			Soil gravimetric moisture content (%)			Soil temperature (^0C)		
	1991	1992	1993	1991	1992	1993	1991	1992	1993
1a	1.23	1.32	1.24	14.1	16.6	16.5	17.6	15.6	19.0
1b	1.40	1.45	1.38	15.8	17.6	17.8	17.1	14.8	18.3
1c	1.55	1.57	1.60	14.6	16.5	18.1	17.0	14.6	17.2
2a	1.23	1.20	1.24	17.2	19.5	18.6	19.0	16.1	19.5
2b	1.34	1.38	1.35	17.0	18.0	19.2	18.5	15.5	19.2
2c	1.54	1.60	1.61	16.5	17.6	18.0	17.9	15.0	18.1

Conventional tillage with mulch application was the most beneficial with respect to reducing soil density.

Simplified tillage caused an increase in soil density and reduced the beneficial effect of mulching. The highest soil bulk density was found in the treatment involving 0-tillage.

Mulching with straw increased temperature and moisture content of the soil in the tillage treatments studied. The highest soil temperature was recorded for conventional tillage, lower for simplified tillage and the lowest was found under the 0-tillage regime.

CONCLUSION

Conventional tillage was found to be the best approach to prepare seedbed for maize under continuous cropping as compared to simplified tillage (disking) and to 0-tillage system. Conventional tillage improves soil physical properties: reduces soil bulk density and increases soil moisture and temperature.

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EFFECTS OF CHANGES IN THE SOIL PHYSICAL CONDITION OF LOESS ON ITS ERODIBILITY

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ABSTRACT

Soil splash and wash by rain drops are the initial phases of soil erosion. A soil's erodibility is a function of complex interactions of soil properties. The moisture content of the soil dictates how soil properties change by rainfall impact, tillage operations and trampling of people and livestock. Soil moisture content continuously changes with time in the soil-plant-atmosphere system due to precipitation, evapotranspiration and drainage. Soil splash from raindrop impact and wash by overland flow are related to penetration resistance, tensile strength, soil bulk density, infiltration rate and soil moisture content.

In a laboratory experiment we studied the effects of cbanges made to the soil physical condition on the erodibility. Only those changes that could be achieved by soil tillage were investigated, using a loess soil from Israel, which was considered to be typical of loess soils found in other parts of the world.

It was found that the bulk density influenced the infiltration rate for rainwater, which in turn had an effect on the erodibility. The moisture content of the soil during compaction (compression) had a strong effect on the resulting soil strength. A strong soil (=high tensile strength) had a higher resistance to splash and wash under simulated rainfall. A distinct optimum was found for soil strength after compression. The moisture content of the soil at the beginning of a rain event had an effect on infiltration and erosion phenomena. It is theorised that pore size distribution of the soil and entrapped air has an important role in erodibility.

INTRODUCTION

Soil erosion by water is a serious problem in many places in the world with different climates and soil types (Crosson and Stout, 1984). Loess soil is of extreme importance as high quality farmland covering almost 10% of the continental area of the world. However, loess has a higb erosivity. soil erosion causes soil to degrade. It is now generally recognised that there is urgent need for adequate erosion control and soil conservation measures in large parts of the world loess belt (de Ploey, 1989). Without a knowledge of the physical processes and factors involved in erosion of a soil type by water it is difficult to develop sound conservation practices, specific to that soil type. The aim of the present study was to achieve a better understanding of how and to what extent each of the various properties of the soil affect its erodibility.

Soil erosion involves two stages: (1) detachment of soil particles and (2) transportation of tbe soil material by erosive agents such as water. Soil detachment by raindrops is the initial phase of the soil erosion process by water (Hussain et al., 1988).

Rainsplash is the most important detaching agent. Raindrop energy serves to break down aggregates on the soil surface and detach soil particles from the mass (Kinnell, 1974). Detached particles are splashed and fall back to the surface in a more dispersed state. This process continues as rainfall proceeds. Consequently, many physical properties of the surface soil change with time, causing soil splash detachment rate to change also with time (Al-Durrah and Bradford, 1982). The amount of soil particles detached from the surface is associated with the mechanical, physical and chemical properties of the soil (Andrew and Mosher, 1970).

Soil moisture content continuously changes with time in soil-plant-atmosphere system due to precipitation, evapotranspiration, drainage and so on. Different moisture contents affect the rate of change of soil properties such as soil mechanical, physical, and chemical properties during rainfall events. Soil erodibility is a dynamic function of complex interactions between these soil properties.

A great deal of work has been already carried out on the processes involved in soil erosion by water, hut little of this relates to the distinctive group known as loess soils which are widespread in China, Soviet central Asia, the Ukraine, Siberia, central Europe, Argentina and the Great Plains of North America.

The present study was carried out to measure penetration resistance, tensile strength, infiltration rate, permeability, splash and wash, using loess soil of root layer used in the experiments from Israel, which was considered to be typical loess soils found in other parts of the world.

MATERIALS AND METHODS

The soil is a buff-coloured loess soil. The texture is a fine sandy loam. Sand make up 52%; silt make up 30% and clay make up 18%. The structural stability is low. A more detailed description of this soil type can be found in another publication (Hillel, 1967). The samples were prepared by sieving dry soil in < 2 mm. All samples prepared with different moisture contents were similar methods. Repetition per treatment was 4 times.

Samples with different moisture contents were measured with a penetrometer, which automatically records penetration resistance on the paper (Smith and Mullins, 1991). Dry bulk density of samples was 1.35 g/cm^3. Cone diameter was 4 mm. The penetration speed was 25 mm/min. Measurement depth from soil surface was 4 cm.

The tensile strength measurement was carried out with an adaptation of the Brasilian method (Dexter and Kroesbergen, 1985). The PVC rings with wet soil were placed under pressure equipment and compacted at a force of 50 kg. After compression, 3 brass rings were placed on the compressed soil, and the discs were pushed into the soil until the top edge was flush with the soil surface. Samples in PVC rings with compressed soil were dried at 75°C for 48 hours. The brass rings with soil from the PVC rings were removed. The soil "discs" were taken out of the brass rings. Discs were placed on its side under the piston of the press. The force at the moment of failure of soil disc was recorded. Bulk density was calculated from weight and dimensions of the discs.

Infiltration rate and permeability of different moisture content samples were measured respectively (Hillel, 1980). Stainless steel rings with height and diameter of 10 cm and 5 cm respectively were used. The height of soil column was 8 cm. Bulk density of samples was 1.35 g/cm^3. A burette provided 0.25 cm water layer for soil column. Infiltration, based on the rate of uptake of water was then calculated. Permeability was tested with the constant head method. Water flowed through the column from 2 cm constant head of water on the soil surface and was collected in the glass.

The experiment of splash and wash test (Bollinne, 1978) were carried out by means of rainfall simulator of the Wageningen Agricultural University. An apparatus used for splash and wash measurement was specially prepared by authors with test objective. A stainless steel ring 8.1 cm and a plexiglass ring 9.2 cm in diameter were used. Distance between the rings was 0.4 cm. The perforated plate allowed the washed soil and water to go into the bottle. The splashed soil was collected in the pail. Under 45 mm/min rainfall intensity and 0.5 mm drop size in diameter from a height of 98 cm, splash and wash of different moisture content samples were measured at 1 minute.

RESULTS AND DISCUSSION

Effect of moisture content on penetration resistance.
Figure 1 shows that penetration resistance is low when soil moisture content is high, and when soil is dry, penetration resistance is bigger. As soil contains more water, soil is becoming to be soft and disperse, both soil internal friction and soil-metal friction are low. In dry soil there will be a higher cohesive force between the particles, and also the steel-soil friction will be higher.

In loess soil, the changes in cone resistance with water content are not linear (Figure 1). The suitable function is $Y=0.71+62.38*\mathrm{Exp}(-X/5.48)$. These results are similar to the results by Campbell and O'Sullivan (1991) where it was found that cone resistance decreased with increasing soil water content in non-loess soils.

Relation between moisture content, tensile strength and bulk density.

Table 1 Effects of water content during compression on tensile strength and bulk density of dried samples.

Moisture content (%)	Tensile strength (kg/cm^2)	Bulk density (g/cm^3)
26.9	0.32	1.45
19.9	0.33	1.48
15.5	0.41	1.50
14.2	0.32	1.32
11.2	0.20	1.22
6.8	0.04	1.12

From Table 1, it appears that tensile strength and bulk density are different at different moisture contents with compression. The tensile strength and bulk density has a correlation index of r=0.93. The tensile strength and bulk density show a maximum at moisture content of 15.5%.

Effect of moisture content on infiltration rate and permeability.
Figure 2 indicates that soil infiltration rate decreases with soil moisture content increasing. Permeability decreases when moisture content increases from 2.4% to 26.9%. Beyond this point, in the moisture content range from 26.9% to 33.6%, permeability increases again. Infiltration will normally decrease during the storm, because of splashing, slaking, crust formation and increasing of soil moisture (Le Bissonnais and Singer 1992). In our experiment, permeability decreased with soil moisture up to 25%. It is to a large extent due to the irregular and composite size and, shapes of soil pores. Maybe during wetting compression of entrapped air influenced permeability.

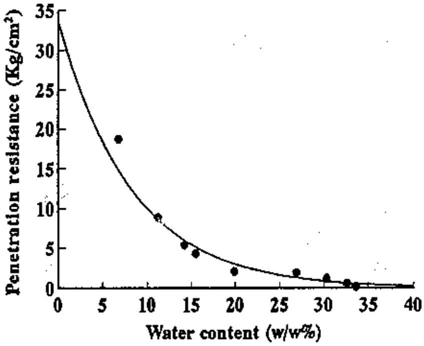

Figure 1 Variation of cone resistance with water content.

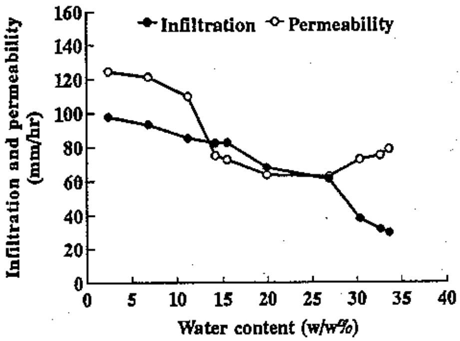

Figure 2 Effects of water content on initial infiltration and permeability.

Effect of moisture content on soil splash and wash under rainfall simulator.
Effects of moisture content on the splash and wash.

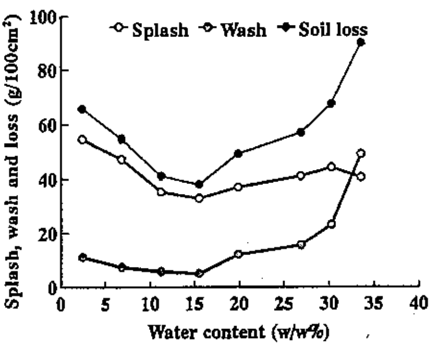

Figure 3 Variation of splash and wash with water content.

Figure 3 shows that different moisture contents affect splash and wash (soil loss = splash + wash). When moisture content is lower or higher, splash is high. The amount of splash is less at moisture content from 11% to 20%. However amount of splash of drier soil is higher than that of wetter soil. From Figure 3 it appears that the amount of soil moved by wash is very high at high moisture content from 20% to 33.6%. Since the binding force between soil particles is low, they are easy to be separated. On the other hand, infiltration rate is low when soil moisture content is high, so runoff is high, then the number of particles washed away with runoff is high.

Amount of splash at moisture contents from about 11% to 20% is low, possibly due to the fact that tensile strength is high. When soil is dry, soil particles are scattered so that splash is high. Dry soil has a high infiltration rate and runoff is low. Therefore wash is reduced in dry soil. But the total amount of splash and wash of dry soil is lower than that of wet soil.

The splash and wash in relation to tensile strength and bulk density.
The relationship of effects of tensile strength on splash, wash and loss of wet soil samples are given in Figure 4. Their correlation indexes of r= -1, -0.61 and -0.97 were calculated respectively. Based on results of measurements, relationship of effects of bulk density on splash, wash and loss of wet soil samples are illustrated in Figure 5, their correlation indexes of r= -0.99, -0.55 and -0.93 were calculated.

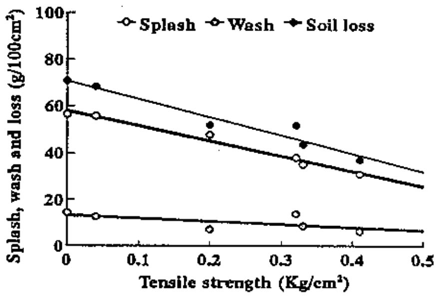

Figure 4 The splash and wash of wet samples soil with compression in relation to tensile strength.

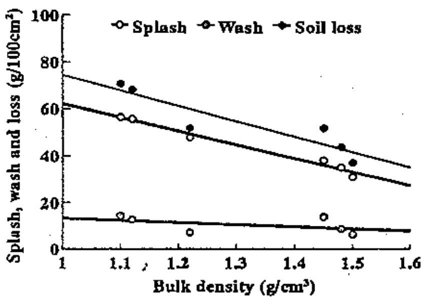

Figure 5 The splash and wash of wet samples soil with compression in relation to bulk density.

Figure 4 and 5 illustrate tensile strength and bulk density in relation to splash and wash. These show that splash and wash are inversely proportional to tensile strength and bulk density, but wash have low correlation to tensile strength and bulk density. Good correlation between clay content, rainfall intensity and erosion were observed by Miller and Baharuddin (1987).

CONCLUSIONS

Soil properties will probably play a major role in the splash and wash process. From the experiments reported here, it is apparent that the erodibility of the loess soil surface changes by changing certain soil properties. When soil penetration resistance, tensile strength and bulk density are high, the soil particles are resistant against the splashing and washing forces of raindrops and soil erosion may be reduced.

The infiltration capacity and permeability capacity of the soil are not a constant but subject to variations with moisture content. The amount of splash of dried soil is higher than that of wet soil, as dried soil particles are apt to detach by splashing. However, the amount of wash of dried soil is lower than that of wet soil. Moisture content and soil properties are influenced by each other over time. Splash and wash are altered by soil properties. Therefore splash and wash are dynamic process due to soil moisture content and soil properties changing in soil-plant-atmosphere system.

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EVALUATION OF THE SOIL STRUCTURAL CONDITION UNDER VARIOUS TILLAGE SYSTEMS IN THE PAMPA HUMEDA (ARGENTINA)

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ABSTRACT

This paper evaluates the effect of different tillage systems upon topsoil structure in the Pampa Húmeda (Argentina). The study was carried out on a Pergamino silt loam on: (A) a long-term experiment in which mouldboard plough (CnT), chisel plough (ChT), disk harrow (RT), and no-tillage (NT) have been continuously compared over 12 years; and (B) plots conducted with CnT and NT for 3 consecutive years either after a 4-year pasture (B1), or after more than 10 years of continuous arable cropping with CnT (B2). The method used was the cultural profile technique, the soil's condition assessment being based on the relative abundance of the structural state Δ, an indicator of degradation by compaction. Bulk densities and porosity systems of the various structural states described were also evaluated. On (A), Δ was highest under CnT (17.5%) and RT (17.4 %), medium under NT (7.8 %), and null with ChT. On (B1), NT maintained the good physical condition left behind by the pasture (absence of Δ), whilst CnT showed 11.5 % of Δ. On (B2), CnT presented scarce degradation signs (Δ<1 %), whereas under NT Δ reached 28.6 %. These results emphasize the important influence of the initial soil physical condition on NT behaviour. The relationship between structural state categories and porosity values is briefly discussed.

INTRODUCTION

Soils of the northern Pampa Húmeda, located between 30° and 35° S lat and 58° and 63° W long, were formed from loess. They are largely Argiudolls, with a silty-loam topsoil followed by a heavy (silty-clay) Bt horizon, slightly acid, and originally well supplied with organic matter. The relief is flat to moderately undulating, with slopes up to 3 %.

Monthly mean temperatures varies from 9°C in July to 23°C in February, the minimum soil temperature never reaching 0°C. Annual rainfall is approximately 900 mm, and concentrates mainly in spring and summer. Rainfall erosivity reaches large values in these two seasons.

Arable cropping is about 120 years old in the area. For a long period, arable crops were alternated with pastures for beef production; this farming system helped maintain soil fertility. Since the 1970s, however, and due chiefly to economic reasons, there has been an important increase in the area under arable crops, the cropped area increased in relation to the pasture area, at an annual rate of 4 % (1). During this last period, primary soil tillage has been basically performed with mouldboard plough, coupled with disk and tine harrows, and rollers for seedbed preparation. The main arable crops in the region are full-season soybeans, wheat, double-crop soybeans and maize.

The former cropping system, under the climatic conditions of the region, has resulted in soil degradation. Typical signs of this are a reduction in topsoil aggregate stability (2); the presence of compacted layers and plough and disk pans in the profile; a significant decrease in organic matter (46.7 %), total N (48.3 %) and available P (76.0 %) with respect to the original contents (3); and a decrease in water infiltration rates (4), which results in increased runoff and water erosion (5). These changes affect both water and nutrient supply to crops, which result in a greater year-to-year yield variability and, in some cases, in lower mean crop productivity (6).

In the last decade, some alternative tillage systems, such us no-till and "vertical" (chisel) tillage started to be tried and disseminated in the region.

The objective of this paper is to evaluate the effect of different tillage systems upon the topsoil structure.

MATERIALS AND METHODS

The study was carried out at the Pergamino Experimental Station on a Typic Argiudoll (Pergamino Series), with a silty-loam (65 % silt; 23 % clay; 12 % sand) A horizon (0-25 cm), followed by a silty-clay-loam B1 (25-34 cm), and a silty-clay B2t (34-95 cm). Two trials were considered:
(A) a long-term tillage experiment conducted with a wheat/double-crop soybeans-maize rotation which had been started 12 years ago after ploughing out a pasture. Treatments compared included "conventional" tillage, based on the mouldboard plough (CnT); "vertical" tillage, chisel plough (ChT); "reduced" tillage, disk harrow (RT); and no-tillage (NT).
(B) Plots with contrasting cropping histories: (B1) a 4-year pasture, (B2) more than 10 years of continuous arable cropping, which were conducted with both CnT and NT for 3 consecutive years.

The effect of the various tillage systems on soil structure was evaluated by using the cultural profile technique (7,8), which consist of a zonation and mapping of vertical topsoil profiles based on the visible porosity of clods and on their spatial arrangement. At the first organization level (visible porosity), the method distinguishes two typical states, i.e. Δ: clods showing high cohesion, with plain aggregate faces , and negligible visible porosity; and Γ: clods with lower cohesion, rough faces and high visible porosity. The second organization level describes the spatial arrangement of the clods in the profile. Thus, the morphological units can be classified into the categories "F", "SF", "SD", and "M" following an increasing gradient of adhesion among aggregates, the latter indicating a massive structure.

Two adyacent profiles (1.5 m width x 0.3 m depth) were characterized in each treatment, by mapping the morphological units and classifying the structure into the two organization leves mentioned above. In this paper only the relative abundance of Δ of the various treatments is compared. This structural state is used as an indicator of the cumulative degrading effects of cropping systems (8).

The bulk density of the various morphological units found in (A) was measured by taking soil cores with a 321 cm^3 (7.15 cm diameter x 8.00 cm height) steel cylinder. Additionally, bulk density was also determined in 79 clods taken from sites (A) and (B2), described as Δ using the kerosene impregnation and hydrostatic weigth method (9) in order to asses the actual volume of structural porosity of this type of clods. Textural porosity was determined in natural 2-3 mm diameter aggregates (10, 11).

RESULTS AND DISCUSSION

The values of relative abundance of Δ found are presented in following table .

Tillage system	Abundance of Δ (%)		
	(A)	(B1)	(B2)
CnT	17.5	11.5	< 1
NT	7.8	< 1	28.6
RT	17.4	—	—
ChT	< 1	—	—

After 12 years of continuously applying the same tillage system, differences in % Δ became apparent. As expected, cumulative effects of CnT (Fig. 1) were the most degradative, together with RT, even when the soil depth affected by the latter is smaller (8-12 cm) than with CnT (15-17 cm). Frequent use of disks usually results in disk pan formation under the conditions of the Pampa Húmeda. NT showed intermediate values of Δ, the compacted zones with this type of aggregates (about 3 cm depth) being preferably located beneath a layer of loose soil and crop residues at approximately 4-6 cm depth (Fig. 2). Under ChT the soil exhibited the best structural condition, with no appreciable degradation signs (Δ state).

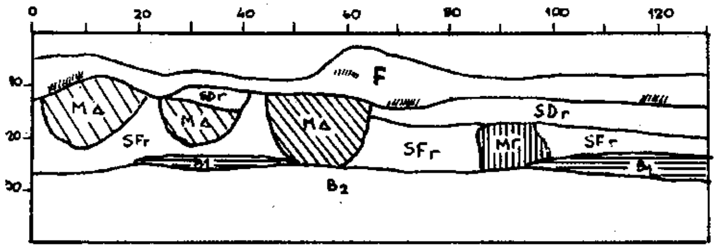

Figure 1. Mapping of morphological units in the ploughed layer in (A) conventional tillage (CnT).

In (B) there seemed to be an important influence of the initial soil condition, influenced by cropping history, on the abundance of Δ, in particular with NT. Under this tillage system, the soil with few years of cropping after a pasture (B1) showed a good structural condition, with minimum degradation signs. Conversely, on the initially degraded soil (B2), no-till presented even higher values of Δ (Fig. 3) than were observed for CnT and RT in (A). On the other hand, in CnT after pasture (B1) % Δ values were found to be slightly lower than the ones observed for the same tillage system in (A). However, and unexpectadly, the Δ state was practically absent after using CnT in the plot with a large number of years of continuous arable, the reasons for this behaviour being obscure.

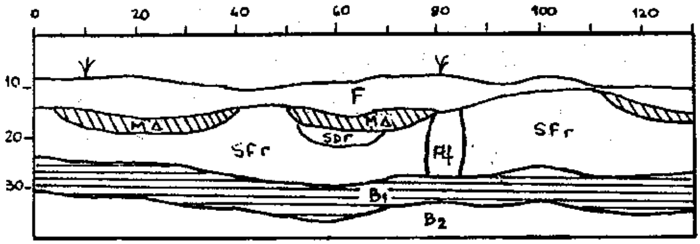

Figure 2. Mapping morphological units in the topsoil in (A) no-tillage (NT).

Except from the value obtained in B2 for NT (28.6%), the relative abundance of Δ encountered in the above trials is markedly lower than those reported by Manichon (8) for different crop rotations in France.

Bulk density results obtained with the core method in the profiles of (A) revealed a trend to increasing compactness in accordance with the grade of adhesion among structural elements described visually (morphological units). Thus, mean bulk density values were 1.01 (n=6; Sn-1= 0.05) for "F"; 1.26 (n=8; Sn-1=0.12) for "SF"; 1.31 (n=2) for "SD"; and 1.40 Mg m^{-3} (n=9; Sn-1=0.04) for "M".

Clod bulk density was 1.480 for (A) and 1.572 Mg m^{-3} for (B2), and ranged from 1.366 to 1.539, and 1.549 to 1.617, respectively. The amplitude of de range (0.1-0.2) is in accordance to that found by Tardieu (12) working with a soil of similar texture at Grignon (France). However, our values are much lower due mainly to differences in organic matter content (Pergamino 3.0-3.7%, Grignon 1.7-2.2%) and in characteristics of mineral fraction. In Pampa Húmeda soils the fine silt fraction made up by 45 % of "fitolitos" with very low actual density (13).

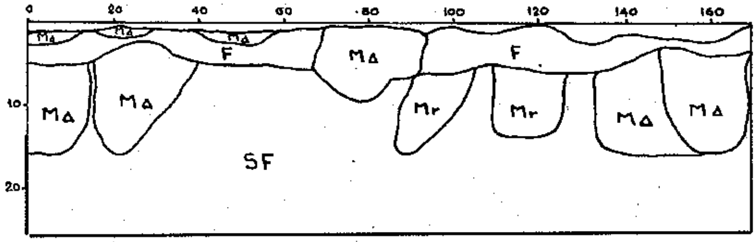

Figure 3. Mapping morphological units in topsoil of no-tillage plot in (B2).

This characteristics causes the textural density values of small (2-3 mm) natural clods take relatively lower (i.e. 1.624 and 1.543 Mg m^{-3} for B2 and A with organic matter content of 3.0 and 3.7 %, respectively.
Bulk density of Δ clods was not correlated with clod size (r=0.0462, n=79). This type of clods showed structural porosity less than 5 % (Fig 4).

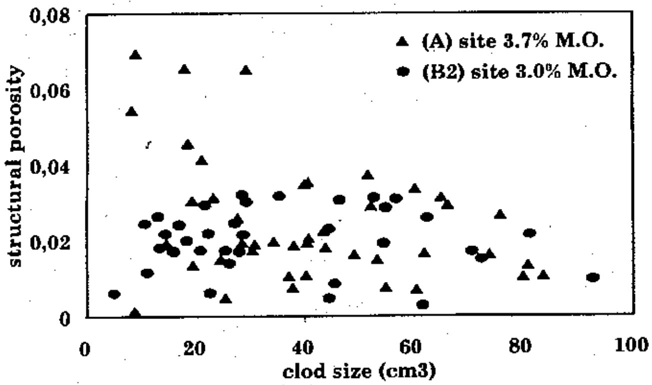

Figure 4. Δ clod structural porosity - clod size relationships.

CONCLUSIONS

CnT and RT cropping systems were more degradative of soil structure by forming compacting layers (plough and disk pans), when the initial physical condition is good (i.e. pasture). In this situation (A and B1) NT was able to mantain a favourable structure, but the opposite is true for NT when the initial condition is already degradated (B2). Thus, the evaluation of the initial state of structure became very important for the succesfully application of direct drill cropping system.

Morphologic description of the structure was correleted to physical measurements (bulk density), and the reduced structural porosity of the Δ clods, used as indicator of structure degradation, was verified.

The cultural profile method proved to be an interesting tool to study the soil-machinary-crop relationships by allowing in one hand, to characterize the spatial variability of the structure and hipotetize about its origin, and in other hand to focul the sampling and measurements of the other physical properties. In addition, this method that does not use expensive equipement, is highly appropiate to be appliedon third word countries, where equipement cost are always a restriction for research.

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SOIL STRUCTURE AND RELATED PROPERTIES OF A CHERNOZEM UNDER CONVENTIONAL AND REDUCED TILLAGE SYSTEM

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ABSTRACT

In a field experiment initiated in 1986, on a chernozem in Iassy, the East part of Romania, aggregate size distribution, hydric stability of soil structure, bulk density, cone resistance and total porosity are being measured on different tillage systems, for winter wheat, soya bean and maize.

The values of these physical properties of the soil oscillated in comparison with the tillage system applied, vegetation stage, depth and the specific technology for each crop.

At winter wheat a more compacted layer was formed at 10-20 cm depth as a consequence of passes for seedbed preparation; at soya bean and maize the same phenomenon appeared after weeds control tillage.

INTRODUCTION

The wheel pressure of tractors and agricultural machines on soil causes significant changes of structure and soil properties not only in the cultivated layer, but in the deeper soil layers as well (1,2). Considerable demage to the structure of agricultural soils has already been caused by mechanical means. There is great need for immediate action in order to stop structural degradation and maintain soil fertility (3, 4).

The purpose of this paper is to look the response of soya bean, winter wheat and maize to the different soil tillage systems in the East part of Romania.

MATERIALS AND METHODS

Soil tillage treatments.

As a setting method, the subdivided plots method was used, with four repetition, aiming to study the following factors:

Factor A - Soil tillage
a_1 - 20 cm ploughing
a_2 - 20 cm ploughing and 10 cm loosening
a_3 - 30 cm ploughing
a_4 - Paraplow
a_5 - Chisel
a_6 - Disk - harrow
Factor B - Cultivated plant
b_1 - soya bean

b_2 - winter wheat
b_3 - maize
After sowing, during vegetation period and at harvesting,we made tests for determining soil moisture, structure units distribution, bulk density, cone resistance and total porosity.

Study of the natural conditions
The territory of experimental farm of Agricultural University of Iaşi is located in the East part of Romania, in the Moldavian plain. The soil is represented by a cambium chernozem, with a good supply of fertilizing elements and organic matter. This soil is irrigated since 1968 and it offer good conditions for the crops. The climate is temperate continental of BS bx type, with a medium rainfall over a year of 510 mm in average and the temperature around 9.6^{0}C.

RESULTS AND DISCUSSION

Influence of soil tillage on hydric stability
The hydric stability of soil structure (table 1) was influenced by soil tillage, specific technology for each crop, vegetation stage and depth.
In case of winter wheat the values of hydric stability increased from sowing to harvesting, in all tillage variants and all over the experimental years, from the surface to the more profound layers. The increase is more significant (7-8 %) during sowing - straw elongation period, going on with a little reduced intensity (3-4 %) up to harvesting.
In case of soya bean and maize, the general tendency was to diminish the values of hydric stability from sowing time until mechanical weed control tillage, followed by a easy progress until harvesting.
The above mentioned phenomens occurred with a big intensity in the 0-10 and 10-20 cm layers and were diminished in the 20-30 cm layer. The values of hydric stability of soil structure were superior to those without ploughing with 4-14 % in the moldboard variants, due to the soil brought from profoundness. The using of disk-harrow led to get the lowest values of hydric stability (39.5 - 59.0 %) in all the layers and all over vegetation stages.

Influence of soil tillage on bulk density
The modification of bulk density show in what measure the state of loosening or compaction, affect the plant development and the level of the crops (table 2).
At winter wheat especially in the dry autumn, due to the repeated passes with seedbed preparation tools, the 10 -20 cm layer is powerfully compacted, the values of bulk density being between 1.28 - 1.33 g\cm^3. During the vegetation period, bulk density values increased on the entire profile at winter wheat.
At soya bean and maize, after maintenance tillage a compact layer was formed to the 10 -20 cm depth with 1.48 - 1.63 g\cm^3 values. Up to harvesting the differences between layers diminish to all the crops; the lowest values of bulk density registering in the variants ploughing at 30 cm and 20 + 10 cm (1.25 - 1.43 g\cm^3).
The highest values were registered when soil was tilled only by disk-harrow (1.50 - 1.57 g\cm^3).

Influence of soil tillage on cone resistance
If the water percentage from soil is uniform, the resistance to penetration is an index of the compaction more sensitive that bulk density. Statement of the soil more sensitive as bulk density, and was used to indicate the effects of soil tillage system over soil conditions.

Table 1 Influence of soil tillage system on hydric stability (%)(1986-1993)

VARIANTS		SOWING			VEGETATION			HARVEST		
		0-10	10-20	20-30	0-10	10-20	20-30	0-10	10-20	20-30
WHEAT	A20	54.83	56.03	59.50	57.96	59.86	61.43	60.10	61.53	62.40
	A20+10	55.10	55.93	57.93	58.00	60.13	60.93	59.90	61.60	62.10
	A30	56.60	57.46	57.80	59.40	60.80	61.50	61.20	62.70	62.80
	PARAPLOW	53.10	54.53	58.83	56.60	59.30	60.80	58.90	60.80	61.53
	CHISEL	52.40	54.40	58.96	56.20	59.36	61.00	58.40	60.70	62.00
	DISK	38.90	42.33	58.30	46.16	49.23	59.40	48.50	51.30	60.76
SOYA BEAN	A20	56.43	59.13	61.06	51.30	56.23	60.43	53.36	57.93	62.63
	A20+10	56.26	59.36	60.43	51.23	56.90	59.96	53.40	58.63	61.40
	A30	57.70	59.90	61.20	52.80	57.73	60.93	54.03	59.50	62.50
	PARAPLOW	55.33	58.26	60.20	48.03	54.96	59.50	51.20	57.26	61.16
	CHISEL	55.26	57.46	59.60	48.83	54.80	59.20	51.00	57.06	60.80
	DISK	44.66	47.20	58.33	40.36	42.30	57.66	42.60	44.73	58.70
MAIZE	A20	56.73	58.60	60.60	50.33	54.73	60.70	52.36	56.23	61.46
	A20+10	56.70	58.93	60.46	50.50	55.76	60.00	52.83	57.20	61.43
	A30	57.60	59.66	61.10	51.50	57.33	60.63	53.50	58.70	62.03
	PARAPLOW	55.10	57.30	60.10	49.30	54.43	59.43	50.80	55.90	60.80
	CHISEL	54.63	57.00	59.83	48.80	53.80	59.20	50.10	55.30	60.56
	DISK	46.53	48.46	57.10	40.40	41.63	56.53	42.63	43.83	58.00

Table 2 Influence of soil tillage system on bulk density (g/cm^3)(1986-1993)

VARIANTS		SOWING			VEGETATION			HARVEST		
		0-10	10-20	20-30	0-10	10-20	20-30	0-10	10-20	20-30
WHEAT	A20	1.14	1.34	1.45	1.32	1.43	1.48	1.40	1.49	1.55
	A20+10	1.14	1.32	1.31	1.31	1.40	1.42	1.39	1.46	1.47
	A30	1.12	1.31	1.28	1.30	1.38	1.40	1.36	1.42	1.43
	PARAPLOW	1.16	1.35	1.32	1.36	1.42	1.44	1.41	1.47	1.50
	CHISEL	1.17	1.36	1.34	1.38	1.44	1.48	1.43	1.49	1.52
	DISK	1.22	1.39	1.45	1.42	1.47	1.50	1.50	1.55	1.57
SOYA BEAN	A20	1.01	1.17	1.48	1.22	1.48	1.57	1.29	1.45	1.58
	A20+10	1.03	1.15	1.25	1.21	1.47	1.43	1.27	1.44	1.46
	A30	1.02	1.14	1.18	1.20	1.44	1.41	1.25	1.42	1.43
	PARAPLOW	1.10	1.26	1.32	1.25	1.48	1.45	1.29	1.47	1.47
	CHISEL	1.14	1.28	1.34	1.27	1.50	1.48	1.30	1.49	1.50
	DISK	1.18	1.33	1.49	1.31	1.60	1.61	1.33	1.62	1.62
MAIZE	A20	1.06	1.16	1.50	1.23	1.50	1.58	1.28	1.48	1.60
	A20+10	1.04	1.14	1.31	1.22	1.49	1.46	1.26	1.46	1.48
	A30	1.00	1.12	1.19	1.20	1.48	1.44	1.25	1.45	1.45
	PARAPLOW	1.08	1.24	1.30	1.28	1.51	1.47	1.31	1.49	1.49
	CHISEL	1.10	1.25	1.33	1.29	1.53	1.50	1.33	1.51	1.52
	DISK	1.16	1.33	1.50	1.31	1.63	1.64	1.35	1.63	1.64

At winter wheat (table 3) we notice that the resistance to penetration had maximum values in the 10 - 20 cm layer, which should be penetrated and from which they take the nutrients and the water, in the immediately following stage, the developing roots. Up to harvesting the values increased in all the variants on the 0 - 30 cm depth, the increase being greater during sowing-straw elongation period in the 0 - 20 cm layer. At soya bean and maize the maximum values were registered after mechanical weeds control tillage (22.0 - 31.2 daN/cm^2).
The 30 cm and 20 + 10 cm ploughing variants determined inferior values of this index to the witness with 1.17 - 3.70 daN\cm^2. The variants tilled by paraplow and Chisel determined intermediate values between ploughing and disk-harrow.

Table 3 Influence of soil tillage system on cone resistance (daN/cm^2) (1986-1993)

VARIANTS		SOWING			VEGETATION			HARVEST		
		0-10	10-20	20-30	0-10	10-20	20-30	0-10	10-20	20-30
WHEAT	A20	11.53	19.33	22.90	18.80	21.60	28.80	21.60	27.10	31.80
	A20+10	11.23	18.40	17.70	18.70	21.00	23.70	21.40	24.70	26.20
	A30	10.56	16.70	15.90	18.10	20.10	21.70	20.50	23.10	25.00
	PARAPLOW	13.66	20.50	18.50	21.40	23.40	26.90	23.20	27.00	28.50
	CHISEL	14.80	21.20	19.40	22.20	24.70	27.50	24.30	27.60	28.80
	DISK	17.20	22.20	23.50	23.70	28.00	29.30	28.90	30.70	33.00
SOYA BEAN	A20	10.13	15.60	30.63	16.00	24.93	32.46	19.16	23.90	33.03
	A20+10	10.10	13.73	19.23	16.30	23.50	22.60	18.22	22.56	24.26
	A30	10.10	12.43	16.83	16.20	21.90	20.30	17.40	20.60	21.83
	PARAPLOW	11.20	18.20	23.36	17.73	26.66	23.83	19.80	26.10	27.60
	CHISEL	13.00	19.30	24.93	18.36	27.83	25.66	21.10	28.36	29.83
	DISK	14.83	22.33	30.30	20.40	31.23	31.30	21.20	33.36	33.70
MAIZE	A20	12.03	15.96	31.20	16.26	25.46	29.96	19.50	24.70	34.36
	A20+10	11.43	14.76	20.80	16.50	24.40	23.86	18.60	23.16	25.10
	A30	11.00	13.93	17.60	16.23	22.56	22.13	17.50	21.06	23.56
	PARAPLOW	12.16	19.20	22.46	18.43	27.06	26.10	20.60	25.43	27.66
	CHISEL	13.60	20.86	26.23	19.06	28.30	27.33	22.46	27.13	30.46
	DISK	15.56	22.73	30.80	21.03	31.23	30.76	23.03	31.93	34.50

Influence on total porosity

In the table 4 are presented the values of total porosity. At winter wheat the highest values registered to sowing, in the 0 -10 cm layer (47.2 - 54.5 %) but they decrease with the depth and from sowing to harvesting. To the superior limit were situated the values from the 20+10 cm ploughed variant (48.3 - 54.2 %), close to these registered to paraplow and Chisel (45.0 - 51.7 %) and to the inferior limit those from disk-harrow variant (47.2 %).
At soya bean and maize after weeds control tillage, a compact layer was created with a very low level of total porosity (34.9 - 39.5 %), in the 10 - 20 cm layer, which was kept until harvesting at a very compacted level.

CONCLUSIONS

1. The hydric stability of soil agregats was influenced by soil tillage system, depth, vegetation stage and the specific technology for each crop. The moldboard variants determined the higher

values of hydric stability and the disk-harrow variants the lowest, all over the depths and vegetation stage.

Table 4 Influence of soil tillage system on total porosity (%) (1986-1993)

VARIANTS		SOWING			VEGETATION			HARVEST		
		0-10	10-20	20-30	0-10	10-20	20-30	0-10	10-20	20-30
WHEAT	A20	53.10	48.40	42.46	48.13	46.10	41.11	45.90	44.06	38.56
	A20+10	53.26	48.36	48.34	49.06	47.26	46.03	47.36	45.25	44.16
	A30	54.15	49.50	50.63	50.28	48.34	47.56	48.38	46.48	45.00
	PARAPLOW	51.70	46.73	47.93	47.46	45.23	45.93	45.93	43.63	42.10
	CHISEL	51.76	45.00	46.40	46.83	44.70	43.90	44.71	43.10	40.76
	DISK	47.23	44.13	41.11	44.80	41.46	41.43	41.43	39.25	37.43
SOYA BEAN	A20	55.40	48.53	39.83	50.40	42.40	38.66	47.96	44.63	37.83
	A20+10	55.60	50.03	48.20	50.96	43.10	43.63	48.90	44.73	42.16
	A30	56.30	51.13	49.36	51.43	44.06	45.23	49.73	47.06	44.10
	PARAPLOW	53.70	47.03	46.03	50.10	42.23	42.33	48.33	43.55	40.76
	CHISEL	51.26	46.20	45.00	48.76	40.40	41.03	47.76	42.06	39.33
	DISK	50.00	42.80	39.13	48.13	38.16	37.70	44.43	37.70	36.63
MAIZE	A20	55.40	49.20	39.46	50.03	38.20	36.96	47.56	38.56	36.13
	A20+10	55.80	49.90	44.26	50.53	38.83	42.30	48.46	39.46	38.40
	A30	56.56	51.10	48.93	51.43	39.53	43.16	48.60	39.90	40.00
	PARAPLOW	55.30	44.50	44.60	48.80	37.90	41.70	46.56	38.70	38.56
	CHISEL	54.86	44.00	42.96	47.90	36.86	39.93	46.03	37.70	36.96
	DISK	50.46	40.60	38.73	47.00	34.93	34.36	44.40	34.86	33.33

2. The bulk density and cone resistance increased from sowing to harvesting, all over the tillage variants and layers. At winter wheat, a compact layer was formed at 10 - 20 cm depth, as a consequence of passes for seedbed preparation. Negative reports existed between these values and the crop yield.

3. The total porosity had at winter wheat the highest values in the 0 - 10 cm layer, these decreasing with the depth and from sowing to harvesting. At soya bean and maize, a compact layer was created after maintenance tillage, maintained up to harvesting at a very compacted level.

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APPROACHES TO EVALUATE ORGANIC MATTER QUALITY IN SOIL MANAGEMENT AND TILLAGE STUDIES

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ABSTRACT

Assessment of soil organic matter is a valuable first step in evaluating the overall quality of a soil. In agricultural systems, soil and crop management can influence soil organic C inputs, while the degree and intensity of tillage can result in varying degrees of soil perturbation and distribution of organic inputs. These management factors can influence soil organic matter quality by changing the proportion of active or dynamic organic matter in relation to total organic matter. In this paper, microbial biomass C, soluble carbohydrate C, and light fraction C were used to provide a cumulative assessment of soil organic matter quality, under soil management and conservation tillage systems for short-term rotations in eastern Canada. Generally, each of the above organic matter fractions characterised a specific facet or role in regard to soil organic matter quality. The ratio of microbial biomass C to total organic C provided a useful measure of organic matter change (index of biological activity) in relation to soil management, while hot-water extractable carbohydrates were correlated with stabilization of soil aggregates. Light fraction C was related to level of crop residue returned to the soil.

INTRODUCTION

Soil quality, in an agricultural context, refers to the degree of fitness of a soil for crop production, specifically its capability or capacity to store, accept, and recycle water, nutrients, and energy (1). Assessment of soil quality involves the characterization of critical soil physical, chemical, and biological attributes that serve as indicators of a soil's capacity or fitness for agricultural production (2). Organic matter is a major attribute of soil quality. Due to its multi-faceted role in soil, organic matter serves as a useful indicator of a soil's capacity for nutrient storage, biological activity, and soil structure (1).

Many processes, common to land management practices, can influence soil quality by directly or indirectly affecting one or more critical attributes. Such processes can degrade (e.g. soil erosion) or aggrade soil quality. Tillage is one soil management tool which can govern both degradative and aggradative processes in regard to soil quality (3). Tillage plays a major role in soil perturbation and distribution of organic matter within the soil profile (4). This has implications for nutrient storage, energy flow and dynamics of soil geochemical cycles, and modification of soil structure.

Organic matter, as a major attribute of soil quality, can itself be characterized into a set of sub-attributes composed of organic matter fractions (1). This allows specific attributes of soil organic matter to be related to a particular function or role of organic matter in soil.

The objective of this paper is to evaluate soil microbial biomass carbon, soluble carbobydrate carbon, and light fraction carbon as attributes of soil organic matter quality in soil management and tillage studies.

MATERIAL AND METHODS

Data used in this paper were obtained from recent tillage experiments, and land management studies, conducted on three soil types in eastern Canada.

Soil management and tillage experiments

Charlottetown fine sandy loam (Orthic Humo-Ferric Podzol)
Three reduced tillage systems, established 3-5 years in Prince Edward Island, comparing mouldboard ploughing and direct drilling for small grains (*Hordeum vulgare* L. and *Triticum aestivum* L.) and silage corn (*Zea mays* L.) were sampled at the 0-5 cm soil depth in October, 1987 (5, 6). The statistical design of each experiment was a randomized complete block with four replicates. Three long-term (10-40 years) grassland (mainly *Phleum pratense* L.) sites were also sampled to provide a comparison of soil organic matter quality.

Normandin silty clay (Humic Gleysol)
A crop sequence, tillage (mouldboard vs chisel ploughing), and fertility (manure vs fertilizer) experiment, established 3 years in Québec, was sampled at the 0-24 cm soil depth in June, 1992 (7). Crop sequences consisted of continuous barley (*Hordeum vulgare* L.) compared to a barley followed by 2 years of red clover (*Trifolium pratense* L.). Cattle manure was applied at 40 Mg fresh material ha^{-1}. The statistical design of the experiment was a split-split-plot with four replicates.

Grenville sandy loam (Melanic Brunisol)
Two adjacent crop residue studies with corn (*Zea mays* L.), established for 3 years in eastern Ontario, were sampled at the 0-15 cm depth in May, 1991. In one study, the corn was harvested for grain and all the above ground material (except for cobs) was returned to the soil. In the second study, the corn was harvested for silage and all the above ground material was removed. All other management practices were the same. Three random areas were used, on each unreplicated study, to obtain soil samples.

Soil analyses
Common techniques were utilized to characterize soil organic matter quality. Soil microbial biomass carbon was estimated, on field moist soil samples passed through a 6-mm sieve, using the chloroform-fumigation technique (5, 8). Hot water-soluble carbohydrates (WSC) and acid-hydrolyzable carbohydrates (AHC) were extracted from < 0.5 mm air-dry soil using water (85°C) and 1.5 *M* H_2SO_4 (85°C), respectively (8). Light fraction was isolated from 2 mm air-dry soil by density fractionation, using a NaI solution adjusted to a density of 1.8 g cm^{-3} (9). Wet sieving was conducted on field moist soil (< 6 mm) to obtain the mean weight diameter (MWD) of water-stable aggregates, as a measure of soil structure (10).

RESULTS AND DISCUSSION

Microbial biomass carbon

Microbial biomass is a key variable of soil organic matter functioning both as an agent for the transformation and cycling of plant nutrients, and as a sink or source of labile nutrients. In regard to the latter, microbial biomass accounts for 1-3% and 2-6% of soil organic C and N, respectively (1). Microbial biomass is a dynamic fraction that quickly responds to changes in soil management and tillage (Tables 1, 2 and 3); is sensitive to various toxicities in soil; and is related to soil structure indices. In addition to providing a labile pool or store of nutrients, the ratio of microbial biomass C to total organic C (ie. proportion of organic C in the microbial biomass) can give a measure of organic matter changes within similar soil types and cropping systems (1, 5).

Table 1 Comparison of organic matter quality and soil aggregation (mean weight diameter: MWD) in tillage systems and long-term grass established on a Charlottetown fine sandy loam. Standard error of the mean: SEM.

Tillage system	Organic C (%)	Microbial biomass C ($\mu g\ C\ g^{-1}$)	Organic C in biomass (%)	MWD (mm)
Mould. ploughing	1.96	154.7	0.80	1.83
Direct drilling	2.31	263.8	1.23	3.01
SEM	0.085	12.87	0.074	0.284
Grassland	4.44	560.6	1.27	5.51

The survey of reduced tillage systems, on fine sandy loams in Prince Edward Island, showed that cropping system had the major impact on soil organic C and organic C fractions (Table 1). Retaining crop residues, under direct drilling, at or near the soil surface significantly increased both organic C and microbial biomass C, compared to conventionally mouldboard ploughed systems. Furthermore, the average proportion of organic C in the microbial biomass of the reduced tillage soils was higher than in the ploughed soils, but similar to that in adjacent long-term grassland soils. Such changes indicate that the reduced tillage soils were accumulating organic matter at the soil surface.

Tillage differences alone, as shown above, can cause a redistribution of organic matter within the topsoil. However, unless tillage differences are also accompanied by significant increases in organic C inputs, reduced tillage alone may not result in an overall increase in soil organic matter. Comparison of chisel and mouldboard ploughing, on a Normandin silty clay, showed that tillage differences only marginally affected soil organic matter content. The factors most influencing organic matter were ranked in the following order: crop sequence, manure amendments, and tillage (Table 2). Differences in crop residue retention (ie. organic C inputs) resulted in significant differences in microbial biomass C, although changes in total soil organic C were negligible (Table 3).

Recently, a study in eastern Canada comparing 22 agricultural soils not subject to significant soil erosion with adjacent forests showed that the mass (based on equivalent soil mass of 3500 Mg ha^{-1}) of soil organic C in the former was depleted by an average 22% (11). Furthermore, microbial biomass accounted for 1.7% and 2.3% of soil organic C in the agricultural and forest soils, respectively. Microbial biomass C was significantly related to soil organic C ($r^2 = 0.69$, $p < 0.01$).

Soluble carbohydrate carbon

The soil carbohydrate fraction represents 5-20% of the total soil organic C and consists of a mixture of complex polysaccharides (1). Carbohydrates in soil, which serve as a readily available source of energy for heterotrophic organisms, originate mainly from plants and microorganisms. The microbial polysaccharide pool, associated with hot-water soluble and dilute-acid hydrolyzable carbohydrates, is related to soil microbial biomass C and is usually also strongly associated with soil aggregation. However, the importance of carbohydrates for soil aggregation is reduced under conditions of high organic matter, high volume of rhizosphere soil, and where vesicular-arbuscular mycorrhizal fungi dominate (12).

Table 2 Comparison of organic matter quality and soil aggregation (mean weight diameter: MWD) in a crop sequence, manure amendment, and tillage study established on a Normandin silty clay. Least significant difference: LSD.

Crop sequence	Management	C-input ($g\ C\ m^{-2}\ y^{-1}$)	Organic C	Microbial biomass C	WSC	AHC	MWD (mm)
			g C m^{-2}				
B-B-B	CP-Fertilizer	87	5347	92	39.8	651	1.50
B-B-B	CP-Manure	192	5848	122	41.6	588	1.65
B-B-B	MP-Fertilizer	94	6511	102	43.0	573	1.76
B-B-B	MP-Manure	199	6649	116	43.5	582	1.76
B-RC-RC	CP-Fertilizer	299	6207	117	43.1	604	2.05
B-RC-RC	CP-Manure	393	7452	141	48.6	684	2.16
B-RC-RC	MP-Fertilizer	282	6130	105	45.0	591	2.01
B-RC-RC	MP-Manure	388	8754	148	54.7	744	2.21
Protected LSD		---	1611	42	8.0	146	0.30

Barley: B, Red clover: RC, Chisel plough: CP, Mouldboard plough: MP, Water-soluble carbohydrates: WSC, Acid-hydrolyzable carbohydrate: AHC.

Soil management differences resulting in concomitant differences in organic C inputs were the main factors influencing soil carbohydrate content, as illustrated by the Normandin study (Table 2). The factor having the greatest impact on organic C input was crop type with red clover supplying an estimated average of 300 g C $m^{-2}\ yr^{-1}$, compared to 100 for barley (mostly roots). Cattle manure contributed about 100 g C $m^{-2}\ yr^{-2}$. Tillage treatments did not significantly influence C inputs as their impact on crop biomass was minimal. Organic matter additions increased soil microbial biomass which in turn promoted the production of aggregate binding carbohydrates.

Differences in water-stable aggregation (MWD) were closely related to organic C inputs ($r = 0.93^{**}$) and the derived fractions of microbial biomass C ($r = 0.75^{*}$) and carbohydrates, especially hot-water soluble carbohydrates ($r = 0.89^{**}$). Tillage had little effect on soil aggregation. However, tillage may significantly impact on soil structural stability when differences in tillage, under similar cropping systems, result in significant organic C redistribution (eg. concentrate crop residues near soil surface) (Table 1). Under these conditions, MWD can be closely related to microbial biomass C (r = 0.95***).

Light fraction carbon

Light fraction is a non-humified fraction of soil organic C consisting of mainly plant residues in an intermediate state of decomposition. Unprotected by soil particles, it serves as a readily decomposable substrate for soil microbes and as a reservoir of plant nutrients (1). About 5-10% of soil organic C can consist as light fraction. Perennial forages, retention of crop residues, and continuous cropping can increase the proportion of light fraction C. A recent comparison of adjacent agricultural and forest soils in eastern Canada (11) showed that light fraction organic C contained a greater proportion of soil carbon in the forest soils (5-15%), compared to cultivated soils (3-10%). The light fraction C is associated in part with the macroorganic matter or particulate organic C, which is contained in the sand fraction (<2000 μm and >53 μm) of the soil (1, 9).

Retention of crop residues tended to increase the light fraction in the corn study (Table 3). Both microbial biomass C and light fraction C responded to residue addition before any change in total organic C. Crop residue retention for a three year period increased the proportion of organic C in the light fraction from 4.2% to 7.1%.

Table 3 Comparison of organic matter quality in a crop residue study established on a Grenville sandy loam.

Crop residues	Organic C ($Mg\ ha^{-1}$)	Microbial biomass C ($Kg\ ha^{-1}$)	Light fraction C ($Mg\ ha^{-1}$)
Removed	35.7 ± 1.5	223 ± 15	1.5 ± 0.1
Returned	35.1 ± 1.3	309 ± 38	2.5 ± 0.1

CONCLUSIONS

Characterization of both total organic C and organic C fractions provides a means to assess soil organic matter quality. The organic C fractions discussed in this paper are labile forms of organic matter subject to relatively rapid turnover in soil. Consequently, they are susceptible to change under modifications in land use practices. Microbial biomass C, soluble cabohydrate C, and light fraction C provided a sensitive data set to describe the multi-faceted function of organic C in soil, specifically in regard to soil structure, nutient storage, and biological activity.

Present studies are continuing to characterize the soil carbon balance in contrasting farming systems in eastern Canada (13). Emphasis is being placed on organic matter fractions susceptible to soil management and tillage effects, and their role in the storage and sequestration of soil C.

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EFFECT OF SEEDBED PREPARATION ON DYNAMICS OF SURFACE SEALING, RUNOFF AND INTERRILL SOIL LOSS ON LOESS SOILS

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ABSTRACT

The objective of this study was to identify the principal factors involved in surface sealing of loess soils, and what means the farmer has to control surface sealing. A representative loess soil was sampled and subjected to rainfall tests in the laboratory with a rainfall simulator. The treatments investigated were mulch rates, microrelief, soil moisture and earthworm channels.

The results confirmed the overriding importance of covering the soil surface with plant residues or cover crops during periods without a crop stand. Soil moisture also affected sealing susceptibility and earthworm burrows diminished runoff from sealed surfaces. In the absence of soil cover, the results show that an increase in aggregate stability and size (expressed as microrelief) will also control surface sealing and runoff formation. However, the relative efficiency of these factors is much lower compared to covering the soil surface with residues.

INTRODUCTION

Soils derived from loess are among the most productive soils in the intensive arable farming regions of Central Europe. However, in the past two decades these soils have been frequently reported to be highly erodible. Structural degradation and depletion of organic matter have led to a marked increase in susceptibility of soils to form surface seals. This is due mainly to excessive tillage, decreasing diversity of crop rotations and lack of organic fertilizer incorporation. On the one hand, this leads to problems in crop emergence. On the other hand, surface seals are a principal cause of runoff and soil loss during periods when the soil surface remains unprotected, as is the case in spring after the seeding of sugar beets or maize (Imeson & Jungerius, 1976; De Ploey & Mücher, 1981; Le Bissonais et al., 1989).

Whereas the farmer cannot take direct influence on rainfall amount and intensity occurring at a particular site, he can alleviate the erosive effect of rainfall impact through several soil management techniques before and during seedbed preparation. Using direct drilling techniques he can vary mulch rates, thus contributing to the direct protection of the soil surface against erosive action of rainfall. Should he continue burying his crop residues by tilling the soil conventionally with a mouldboard plough, he can increase the roughness of surface microrelief by decreasing intensity of secondary tillage. Other soil factors exerting influence on dynamics of surface sealing (aggregate stability, biological activity) can only be controlled indirectly through the degree of soil cover and incorporation of organic matter.

To date, comparatively little information is available with respect to the relative efficiency of the various techniques of seedbed preparation in terms of diminishing the risk of runoff generation and interrill soil loss due to surface sealing. Therefore, the objective of this study was to identify the principal factors involved in surface sealing of loess soils following different methods of seedbed preparation. This was done by subjecting a representative loess soil to rainfall tests in the laboratory with different treatments designed to simulate direct and indirect seedbed preparation effects on the above interrill erosion processes. Several runoff parameters were then chosen to reflect the different sealing behaviour of the various treatments.

MATERIALS AND METHODS

Soil and treatments studied

A representative soil from the hilly loess regions of southern Lower Saxony (Germany), classified as an eroded silty Haplic Luvisol (FAO) was selected for the study. Approximately 1500 kg of soil from the 0-10 cm layer was collected about eight weeks after conventional seeding. Organic carbon content was 0.94 %, pH value in $CaCl_2$ was 7.4 and texture was loamy silt (2 % sand, 82 % silt and 16 % clay).

The treatments consisted in varying the conditions of the soil surface of subsamples filled into runoff boxes, in an attempt to simulate the action of different seedbed preparation techniques. Four different treatments were studied:

1. simulating the effect of mulch by covering the soil surface in the runoff boxes with varying amounts of straw mulch, at rates equivalent to 0, 0.5, 1.0, 1.5, 2.0 and 4.0 t ha^{-1}.
2. simulating the indirect effect of mulch on soil moisture by varying moisture of a bare soil surface, in one case keeping the surface moist (20 % w/w), in the other case letting the top 30 mm of the soil surface attain air dryness (3 % w/w). In both cases the soil had similar moisture in the depth range 70 - 300 mm (water potential at approximately 100 hPa).
3. simulating the effect of secondary tillage intensity on surface microrelief by filling the soil into the runoff boxes through sieves of different openings (fine microrelief = 10 mm, medium microrelief = 25 mm, rough microrelief = 50 mm).
4. simulating the indirect effect of tillage intensity on earthworm activity by varying the number of artificial earthworm burrows formed through an already present seal with a rod 5 mm in diameter. Treatments were 0, 2, 4, 6, 8 and 10 channels per 0.2 m^{-2}.

All four treatment series were replicated three times, slope was uniformly maintained at 5 %, soil surface had a medium microrelief (with the exception of the two additional microrelief treatments in series 3) and rainfall intensity was 30 mm h^1 (with the exception of series 1, where intensity was 38 mm h^{-1}, and in series 4, where an additional rainfall run with 60 mm h^{-1} was carried out). Soil surface was always air dry at the onset of rainfall (with the exception of the additional moisture treatment in 2).

Runoff and sediment yield measurements

For all treatments, interrill runoff was determined in the laboratory following the application of simulated rainfall onto runoff plots in boxes 0.9 x 0.8 x 0.4 m in size, into which the soil had been packed in a standardized manner. To avoid artefacts due to splash export, a buffer zone of 0.2 m width was maintained and runoff was collected from an inner plot 0.4 x 0.5 m, only. Runoff measurements were taken at 2-minute intervals. The sediment contained in the runoff was collected at 6-minute intervals and weighed after drying in an oven at 105°C. The simulator produced rainfall with a unit kinetic energy of 25.78 J m^{-2} mm^{-1} and a median drop diameter of 2.9 mm. Variation of intensity over time was less than 1.0 mm h^{-1}. Mean electrical conductivity of the rainfall water was 54 µS mm^{-1}. Further details concerning the rainfall simulator and the runoff boxes can be obtained elsewhere (Roth and Joschko, 1991; Roth and Helming, 1992).

RESULTS AND DISCUSSION

Effect of different mulch rates

The effect of varying mulch rates on degree of soil cover and selected runoff and soil loss parameters is presented in Table 1. Soil cover ranged from 0 to 95 %. Mulch rates had a pronounced effect on sealing dynamics, as both the amount of rainfall necessary to initiate runoff as well as the runoff rate after 20 mm of rainfall were significantly affected by degree of soil cover. In the first case, soil cover showed a positive linear relationship to runoff initiation ($y = 0.08 \cdot x + 3.58$; $R^2 = 0.95$***), while runoff rate after 20 mm of rainfall was negatively correlated to soil cover using an exponential fit ($y = 28.11 \cdot \exp(-0.0414 \cdot x)$; $R^2 = 0.99$***). The effect of soil cover on soil loss is even more pronounced, again best described by an exponential function ($y = 127.27 \cdot \exp(-0.0820 \cdot x)$; $R^2 = 0.97$***). These results confirm results obtained by others using either natural or simulated rainfall in the field (e.g. Mannering & Meyer, 1963; Kainz, 1989). Owing to the exponential decrease of soil loss as a function of soil cover, comparatively small amounts of mulch already enable an overproportional reduction in soil loss. Results in Table 1 indicate that approximately 35 % of soil cover can lead to a sixfold reduction in interrill soil loss. This is a degree of soil cover currently achieved in mulch seeding techniques propagated for the drilling of sugar beets and maize in Germany (Kainz, 1989; Brunotte, 1990).

Table 1: Effect of different mulch rates on rainfall amount necessary to initiate runoff and effect on runoff rates and total soil loss after 20 mm of simulated rainfall (rainfall intensity 38 mm h^{-1}).

Mulch treatment ($t\ ha^{-1}$)	Degree of soil cover (%)	Rainfall required to initiate runoff (mm)	Runoff rate after 20 mm rainfall ($mm\ h^{-1}$)	Soil loss after 20 mm rainfall ($g\ m^{-2}$)
0	0	3.8	24.8	89.2
0.5	15	5.2	15.5	37.2
1.0	35	6.2	6.8	15.2
1.5	55	8.8	3.9	1.3
2.0	70	8.5	1.9	0.3
4.0	95	12.8	0.5	-

Effect of soil surface moisture content

Runoff and interrill soil loss are also greatly affected by moisture of the soil surface, as can be gathered from the results presented in Table 2. Maintaining the soil surface at a moisture equivalent to field capacity (100 hPa) induced an earlier begin of runoff, but runoff rates were distinctly lower when compared to the air dry surface treatment, especially after greater amounts of rainfall (40 mm) had provoked a more pronounced sealing of the surface. Whereas the effect of moisture reduced runoff rates by a factor of 2 or 3, soil loss after 40 mm of rainfall was reduced by a factor of about 10.

Table 2: Effect of soil surface moisture content (top 10 mm) on rainfall amount necessary to initiate runoff and runoff rates and total soil loss after 20 mm and 40 mm of simulated rainfall, respectively (rainfall intensity 30 mm h^{-1}).

Soil moisture treatment	Rainfall required to initiate runoff (mm)	Runoff rate after 20 mm ($mm\ h^{-1}$)	Runoff rate after 40 mm ($mm\ h^{-1}$)	Total soil loss after 20 mm ($g\ m^{-2}$)	Total soil loss after 40mm ($g\ m^{-2}$)
Air dry soil surface (3% w/w)	17.7	5.0	20.1	4.1	134.8
Moist soil surface (20% w/w)	8.9	3.4	7.5	3.8	13.9

These results aggree well with the observations made by Le Bissonais et al. (1989). The effect of moisture on surface sealing is attributed to greater stability of moist aggregates as compared to air dry aggregates, as the slaking of aggregates due to compressed air does not take place in moist aggregates. At the same time, particles delivered by aggregate breakdown are coarser, so that seal composition following aggregate breakdown under moist conditions will provide for a greater porosity than when compared to air dry conditions.

Certainly it would not be feasible for farmers to try and control surface moisture directly as a means of reducing erosion risks. Yet the results indicate that other measures leading to higher moisture at the soil surface by reducing evaporation, such as mulching or planting cover crops may also contribute indirectly to control of runoff, because sealing susceptibility is greatly reduced. On the other hand, once the soil is sealed, higher moisture contents will invariably lead to earlier runoff generation.

Effect of surface microrelief

The effect of microrelief on rainfall necesssary to initiate runoff, runoff rates and soil loss are reported in Table 3. Augmenting the surface roughness by increasing size of aggregates led to a reduction of sealing, so that the rainfall amount to runoff initiation increased, while the runoff rates after 20 and 40 mm of rainfall were significantly decreased. Soil loss values were also affected in a similar manner. However, microrelief effects on runoff rates and soil loss were more pronounced after 20 mm of rainfall than after 40 mm, the ratios of fine to rough microrelief decreasing from approximately 20 to 1.5 in both cases. Comparable results of microrelief effects on surface sealing have also been reported by Freebairn et al. (1991).

Table 3: Effect of surface microrelief on rainfall amount necessary to initiate runoff and effect on runoff rates and total soil loss after 20 mm and 40 mm of simulated rainfall, respectively (rainfall intensity 30 mm h^{-1}).

Soil microrelief treatment	Rainfall required to initiate runoff (mm)	Runoff rate after 20 mm (mm h^{-1})	40 mm (mm h^{-1})	Total soil loss after 20 mm (g m^{-2})	40mm (g m^{-2})
Fine surface (10 mm sieve)	15.4	10.5	23.2	14.6	156.4
Medium surface (25 mm sieve)	17.7	5.0	20.1	4.1	134.8
Rough surface (50 mm sieve)	19.5	0.5	14.7	0.7	108.5

Two interpretations to explain the effect of microrelief can be taken into consideration. In the first case, according to Farres (1978), the effect can be attributed to the fact that large aggregates (rough surface) take longer to break down, as slaking takes place at a slower rate. This explanation would hold if all aggregates in the rough treatment were of the same size, i.e. if the rough microrelief were composed solely of big aggregates. However, in the present case, all three microrelief treatments consisted of mixtures of aggregate sizes, varying from 0 to 10 mm, 0 to 25 mm and 0 to 50 mm, respectively. Although there were increasing amounts of big aggregates present in the medium and rough treatments, a greater proportion of the aggregates was smaller than 10 mm in all three cases.

Therefore, we offer the following explanation. Changes in microrelief induce a change in specific soil surface area. This means that rainfall energy and amount is dissipated over a larger surface area. Because rainfall amount and also energy is commonly based on m^{-2} map area, overestimations of effective rainfall will occur. If runoff is plotted not as a function of cumulated rainfall per m^{-2} map area, but rather as a function of cumulated rainfall per m^{-2} of effective soil surface as determined by microrelief, differences between total runoff curves are no longer visible. For a more detailed account of the calculation procedures involved, the reader is referred to Helming et al. (1993). These authors also showed that depressional storage is negligible, and will not explain the observed microrelief effects on runoff.

In practical terms, the use of modern sowing machines in combination with reduced intensity of secondary tillage will provide for a reduction in sealing susceptibility, but the effect will last only for the duration of a few rainstorms when compared to mulch covered soil. This, however, may in many cases be sufficient protection. The technical means of reducing intensity of secondary tillage and seedbed preparation have been extensively discussed by Brunotte (1990).

Effect of artificial earthworm channels

Results on the effect of artificial earthworm channels formed through the surface of an already present surface seal are shown in Table 4. For the two rainfall intensities studied, there was a significant decrease of runoff rate with increasing number of channels. In both cases, highly significant linear regressions were found (30 mm h^{-1}: $y = -1.18 \cdot x + 23.4$; $R^2 = 0.96^{**}$; 60 mm h^{-1}: $y = -1.83 \cdot x + 49.6$; $R^2 = 0.96^{**}$).

Table 4: Effect of artificial earthworm channels (5 mm diameter) formed in an already present and moist surface seal on runoff rates for two rainfall intensities.

Number of artificial earthworm channels per 0.2 m^{-2}	Steady state runoff rates at 30 mm h^{-1} rainfall intensity (mm h^{-1})	Steady state runoff rates at 60 mm h^{-1} rainfall intensity (mm h^{-1})
0	24.7	48.8
2	20.7	45.1
4	17.5	44.2
6	15.8	40.0
8	13.8	33.5
10	12.6	31.0

The beneficial effect of earthworm channels on absorbing runoff has recently been discussed by Roth & Joschko (1991). They pointed out that to remain effective, the burrows have to be continuous and remain open at the soil surface. The latter condition is fulfilled for burrows with diameters > 5 mm. Earthworm activity has been shown to increase with decreasing tillage intensities and the presence of crop residues on the soil surface, meaning that a farmer can also reduce detrimental effects of surface sealing indirectly by choosing less intensive methods of tillage (chisel ploughing, no-tillage), seedbed preparation (one pass instead of two passes with secondary tillage implements) and retaining some form of soil cover (mulch seeding) (Brunotte, 1990).

CONCLUSIONS

From the results presented here it can be concluded that the most effective means a farmer has of reducing the risk of soil surface sealing and crusting is the maintenance of sufficient soil cover using mulch. The direct beneficial effect of mulch by protecting the soil surface against rainfall impact forces is further enhanced by indirect effects such as the reduction of evaporation, thus preserving soil moisture at the surface and decreasing the suceptibility of aggregates to slake. Moreover, crop residues retained on the soil surface will increase superficial burrowing activity of earthworms, reducing the detrimental effects of surface seals once they have been formed. Mulch rates equivalent to 1.0 t ha^{-1}, providing at least 35 % cover, appear sufficient to reduce erosion risks to a tolerable level. Such mulch rates are easily achieved by mulch seeding into residues of winter cover crops commonly planted in Germany (phacelia, vetch, mustard).

For farmers that prefer to continue using conventional tillage methods of seedbed preparation, an alternative lies in establishing seedbeds with a rough microrelief, as there is no need for preparing a very finely aggregated seedbed over the whole surface of a field. It would be sufficient to do this solely in sowing rows, preserving bigger clods in between rows. Recent developments in commercially available implements for secondary tillage allow for differential tillage intensity between and in rows, making such an approach feasible. However, the efficiency in terms of erosion control is much smaller than in the case of mulch drilling.

The above conclusions are based on laboratory measurements, and require further verification in the field, especially with respect to the minimum amount of soil cover necessary to reduce sealing and crusting sufficiently to avoid runoff and soil loss, specifically for different soil types and crop rotation systems. Furthermore, field studies to confirm the effect of natural earthworm channels on runoff reduction appear necessary.

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DIFFERENT SOIL TILLAGE EFFECT ON STABILITY OF DERNO - GLAY SOILS

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ABSTRACT

The investigations were carried out in a derno - gley loamy soil of average tilth. The following tillage was applied for the fall tillage: 1. ploughing in 0-25cm depth; 2. shallow ploughing in 0-15cm; 3. deep chiseling in 0-30cm; 4. shallow chiseling in 0-15cm; 5. minimum tillage in 0-15cm;.
Bulk density in ploughing variants from spring to the end of plant vegetation period has increased from 1.30 g/cm^3 to 1.58 g/cm^3. During the whole plant vegetation period soil bulk density in 3rd, 4th, and 5th variants in 0-20cm layer increased from 1.28 to 1.43g/cm^3. Considerable changes of bulk density depend on the organic materials in the different soil layers. The main mass of plant root was accumulated in these ploughed layers. Soil micromorphological investigations indicated different changes of soil structure. A better soil microstructure was formed in the soil tillage, which were ploghed, i.e. turf layer was turned over.

INTRODUCTION

To optimize soil biological system functioning and to choose an optimum soil tillage, it is necessary to take into account both harvest of the cultivated cultures, weed distribution, soil physical and chemical features and soil microbiological processes as a very important ecologically sensitive soil fertility factors, conditioning organic matter mineralization and humification. Soil tillage change soil density, organic matter distribution, air, water and therefore, effects upon soil microorganism activity. References concerning the above discussed objects are not numerous and rather contradictory. The optimal soil tillage depends upon soil and climatic conditions. Soil tillage destroys the soils and especially increases soil bulk density which destroys soil bulk density accumulates in the soils with expanding tendency. (1,2,3)

MATERIALS AND METHODS

The investigations were carried out at the Experiment station of the Lithuanian Academy of Agriculture, in a derno - gley loamy soil of average tillage. The following tillage was applied for the fall tillage: 1. ploughing in 25cm depth; 2. shallow ploughing in 15cm; (1,2 - turf layer was turned over) 3. deep chiseling in 30cm; 4. shallow chiseling in 15cm; 5. minimum tillage in 15cm; (3,4,5 - turf layer was not turned over).
The following agrocenoses were used for the investigations: permanent grasses (Phleum pretense + Trifolium pratense) of 1 or 2 cultivation years; barley (Hordeum vulgare L.) sort Auksiniai, winter wheat (Triticum aestivum L.). Soil agrochemical characteristics: humus 2.5 %; potassium - 300 mg/kg; phosphorus - 200 mg/kg soil. A particular attention was payed to the changes of the edaphic conditions in certain

experiment variants. The soil chemical properties, that is the amount of humus was determined by Tiurin method, and potassium, phosphorus - by means of accepted standard methods. Soil humidity was investigated by A.Rode (A.Rode 1965).

The microbiological investigations have been carried out every year in the beginning and at the end of plant vegetation period in 0-15 and 15-30 cm soil layers. A distribution of different group microorganisms, as well as activity ferment urease, protease and invertase were determined by means of dilution method.

Micromorphological soil porosity, structure, humus foms, soil thin sections were prepared and described using the methods and concepts of Yarilova and Parfionova (1977), Tursina (1982), Medvedev (1981) as well as according to the methods of Fitzpatric (1984).

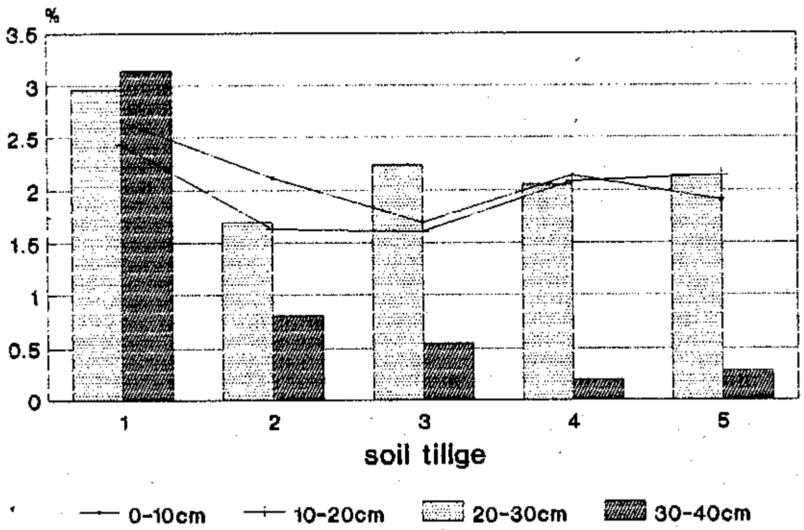
RESULTS AND DISCUSSION

The obtained investigation results indicated, that when ploughing in 25 cm depth, bulk density in 30 cm layer fluctuate between 1.20 g/cm3 and 1.55 g/cm3, while minimum tillage is being applied it reaches 1.30 - 1.60 g/cm3. Soil bulk density from spring tillage to the end of plant vegetation period has increased from 1.30 to 1.58 g/cm3 in barley and winter wheat plots and slightly changed in permanent grass plots (1.35 - 1.45 g/cm3). During the whole plant vegetation period soil bulk density in 3rd, 4th and 5th variants in 0-20 cm layer increased from 1.28 to 1.43 g/cm3, while in 20-30 cm layer - from 1.39 to 1.66 g/cm3. A lager amount of humidity in soil was accumulated in the 3rd variant of permanent grass plots (13 %) and a smaller amount - in 2nd, 4th and 5th variants (11.5). Permanent grass mixture humidity regime of all variants in investigated 4 (0-40 cm) layers fluctuated within the limits of reliable difference (11-12%). In barley and winter wheat plots the largest soil humidity amount accumulated in separate layers of the 1st and 3rd variants - 12.8% (20-30 cm) and 12.1 % (30-40 cm), accordingly, in other layers - from 7.8 to 8.7 %. In the 4th and 5th variants the higher soil bulk density was observed, because organic matters, which accumulated during vegetation period, didn't get into deeper layers. When the surface soil layer wasn't turned over (3-5 variants) all biological residues and plant root system remained on the surface (0-10 cm) layer, i.e. they didn't get into deeper layers (1 table).

Table 1. Underground phytomass of winter wheat g/m^2

soil layer (cm)	variants				
	1	2	3	4	5
0-5	693.1	555.5	535.3	438.6	345.1
5-10	83.5	57.7	79.9	98.2	55.1
10-15	59.3	37.7	41.7	46.6	27.3
15-20	37.5	23.9	22.6	22.4	10.4
total	873.4	674.8	679.5	605.8	437.9

pic.1. humus in different soil layers



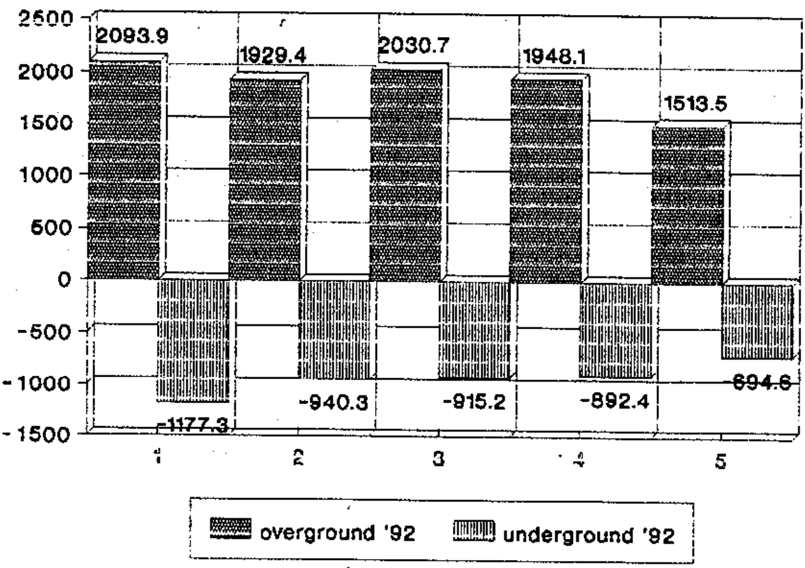
Humus amount tests (pic. 1) in 0-40 cm layer every 10 cm indicated, that in the 1st and 2nd variants it has distributed all over the tillage layer, while in the 3rd, 4th and 5th variants in deeper layers humus amount was rather small.

Plant root system reacted immediately to slight changes of edaphic conditions. Due to deficiency in biologically active matters in deeper soil layers microorganism activity slowed down. After investigation of agrocenoses reaction to bulk density, a direct dependence between plant root morphological and quantitative changes and edaphic conditions effect on plants was determined. A smaller amount of plant root mass accumulated in the 2nd and 5th variants in 0-20 cm depth (the main mass in 0-5 cm), i.e. where the groth conditions were unfavourable. A tendency of decreasing mass in large plant root and increasing mass in small roots of plants was observed in the 3rd, 4th and 5th variants. A slightly changed bulk density, soil humidity regimes and mineraliztion procces in these variants improved small root formation, but deteriorated large root formation.

Main roots of summer rape and clover formed more lateral roots. Main roots were shorter in the 2nd, 4th and 5th variants. According to morphometric data it was indicated, that primary growth conditions have a great effect upon root formation and harvest quality. Biochemical analyses of barley and winter wheat grains indicated, that a larger amount of cellular and Ca, P, K elements accumulated in the ploughing and chiseling. In these variants summer rape seeds contained a smaller amount of harmful erucic and linuronic fatty acids, while in the 2nd, 4th and 5th variants the increasing tendency was observed. The largest amount of agrophytocenoses underground phytomass was registred in the 2nd, 4th, and 5th test variants and it was 15 % higher to compare with the 1st and 3rd variants.

Soil ploughing in 25cm depth made the same favourable conditions for microbe cenoses both in the upper (0-15cm) and the bottom (15-30cm) soil layers. The same root mass distribution in 0-25cm layer and the highest amount of organic mater were observed there, too. Soil tillage minimalization, as well as chiseling in 30 cm depth conditioned a quite evident differentiation of microbe amount in the investigated layers. In the depth of 0-15 cm layer of these variants, and especially in the 5th variant, a considerably higber amount of nonspores-forming bacteria (ammonificating, assimilating mineral nitrogen and nitrogen bacteria), actinomyces and mucedinous fungi were registred, while in 15-30 cm layer their development was evidently reduced to compare with a normaly ploughed soil layer. On the other hand, the highest amount of spore - forming bacteria was observed in the 1st variant, and the lowest amount - in the 3rd and 5th variant soil and there was no distinct differentiation between layers. Aplication of the discussed - above soil tillage methods increase soil bulk density and decrease biological productivity of agroecosystems (Fig.2).

pic.2. Triticum aestivum L.agroecosystem biological productivity g/m2



Soil micromorphological characteristics

The soil forming matrix of silty clay loamy soil is mainly of rinsed morainic origin. The structure of soil is aleuritic with small interfaces of clay and humic peds.
The soil matrix according to Brewer (1964) consists of augular fragments rarely half - polished quarz grains (75 - 80 %), fieldspaths with small hydrated biotite admixtures and biotite - cross - schists. Besides, the soil matrix contains characteristic to these soils accessory minerals, such as tourmaline, zirkone, granite, epidote, etc. Dominate small aleuritic fractions of particles (0.01-0.1mm) and granulated sand (0.1-0.25mm) with small amount of admixture of layer particles. The particular investigations indicated that soil tillage destroys natural soil structure formed for long time of different endogenic and exogenic factors. Soil peds form certain aggregates with clearly oriented system of pores. This soil structure distinguishes itself for higher resistance to different technogenic activity. The investigations on non-tillaged soil have been carried out since 1978. It was determined, that during this period a good oriented structure with a considerably less amount of humus and organic matters in the deeper layers (20-35 cm) has formed. Clayey aleuritic soil mass was expressed in forms of small grains and micro aggregates. Slow reactions of mineralization, oxidation and reduction were indicated by plant residues with a well preserved anatomical structure. In all soil tillage variants dominated humic colloidal plasma.
Ploughing has made favourable conditions for equal distribution of organic matters. The dominating humus form is of mull and moder type which together with soil develop a favourable medium to plants from the stand point of nutrition. Soil chemical analyses have proved this. Soil tillage without turning over the surface layer slows down organic matter mineralization processes under effect of which complicated soil oxidation - reduction processes go on. Slow biochemical processes slow down primary successions and soil evolution. Under these conditions Triticum aestivum, Phleum pratense, Trifolium repens agroecosystems accumulate lower harvest. Besides, we have decreasing biological productivity regulating stability of agroecosystems and agrolandscape.

CONCLUSIONS

Changes of agroecosystems under different fall tillage were determined by means of the experimental investigations. The obtained results indicated, that from the ecological point of view ploughing in 25 cm depth is well - founded, because it decreases soil compaction, improves soil structure, soil humidity regime in the whole tillage layer. In this layer (0-25 cm) accumulated the major root mass of the investigated agroecosystems, in the rhizosphere layer the amount of humus increased and microorganisms became more active. This soil tillage method promoted the development processes in the soil. Soil loosening by chisel (0-30 cm) gives the similar results as ploughing, however, its annual usage in the deeper soil layers decreases humus to 0.7%. Chisel tillage is more effective in erosive soil, because plant organic residues on the soil surface decreases negative effect of spring water. From the

ecological point of view shallow ploughing, shallow chiseling and disk - cultivation is ungrounded.

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PHYSICAL INDEX A GUIDE FOR TILLAGE REQUIREMENTS

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ABSTRACT

Tillage requirements of Ustipsamment, Chromustert, Haplustalf, Ustorthent, Ustochrept were determined by the use of tillage rating system and physical index. The physical constraint analysis was carried out by arranging the score of each component of physical index in an ascending order. The specific soil physical constraints, slope and mean annual rainfall for each soil were matched with an appropriate tillage system. The adoption of matched tillage systems improved the physical conditions of the soil and increased significantly the yields of rainfed sorghum, soybean, pearl millet, maize, black gram, groundnut, tomato and castor crops, and irrigated sorghum, tapioca, rice and wheat crops, under farmers level of management.

INTRODUCTION

Tillage objectives vary with soil and climatic conditions prevailing within a region. An "Expert System" based on management science decision techniques was developed (1) for the identification of an appropriate conservation tillage practice for corn and soybean and a "Tillage Rating System" based on soil and climatic conditions was developed (2) to identify the regions suitable for No-tillage system and for maintaining a protective cover of residues from the previous crop on the surface of coarse textured and self mulching soils. In the semi-arid and arid regions of India, soils have very low organic matter,low biological activity, impeded internal drainage and shallow depth. The puddling of the soil to reduce water loss by deep percolation from rice fields has further deteriorated the soil environment, especially for the succeeding upland crops. The tillage requirement of a few such soils was determined by first analysing the soil physical constraints by the use of "Physical Index" and then matching them with an appropriate tillage system.

MATERIALS AND METHODS

Soils varying in texture from loamy sand to clay and belonging to orders Entisol, Vertisol, Alfisol and Inceptisol were used in the study (Table 1). Horizonwise undisturbed soil samples 70 mm in diameter and 80 mm in length were used for the determination of bulk density and saturated hydraulic conductivity and soil samples 50 mm in diameter and 20 mm in length were used for the determination of non-capillary pore space and water retention characteristics. Soil texture was determined by the Hydrometer method and organic matter by the standard chemical method. The depth of ground water was greater than 1.5 meter and soil slope was less than 1% for most of the soils except Ustorthents in Andhra Pradesh. Physical Index was calculated by taking product of the rating of eight pertinent physical properties of soil (3).

Table 1. Pertinent physical properties for some soils of India.

Physical Properties	Entisol# Ustipsamment Rajsthan		Vertisol Chromustert Tamil Nadu		Alfisol Haplustalf Tamil Nadu		Entisol## Ustorhent AndhraPradesh		Vertisol### Chromustert MadhyaPradesh		Inceptisol Ustochrept Punjab	
Surface texture Soil depth (cm)	Loamy sand >150		Clay 115		Sandy loam 105		Loamy sand 43.6 (7.6)		Clay 178.0 (18.5)		Silt loam 150	
	D	M	D	M	D	M	D	M	D	M	D	M
Bulk density (Mg m(-3)	0-15 15+	1.51 (0.01) 1.54 (0.02)	0-15 15-30 30+	1.12 (0.01) 1.15 (0.02) 1.25 (0.02)	0-19 19-42 42-60 60+	1.48 (0.02) 1.77 (0.02) 1.80 (0.02) 1.68	0-16 (7) 16-43 (6)	1.58 (0.06) 1.57 (0.05)	0-20 (1.0) 20-55 (8.5) 55-112 (5.6) 112-178	1.45 1.54 (0.08) 1.56 (0.09) 1.62	0-13 (0.08) 13-25 25-41 41-99	1.32 1.77 1.68 1.58
Ka (cm/hr)	-	13.6 (1.7)	-	2.73	-	4.43	-	14.21 (2.88)	-	1.133 (0.174)	-	0.029
WSC (cm/m)	-	9.24	-	16.80	-	12.25	-	3.95 (0.66)	-	25.15 (3.56)	-	19.82
OM (%)	0-15	0.30 (0.02)	0-15	0.6	0-19	0.80	0-16	0.470 (0.270)	0.20	0.705 (0.190)	0-13	0.725
NCP (%)	0-15 15+	33 21	0-15 15-30 30-60	3.0 1.9 1.9	0-19 19-42 42-60	18.6 8.5 10.5	0-16 16-43	20.5 16.8	0-20 20-55	2.4 2.0	0-13 13-25 25-41	10.8 5.6 6.8
Groundwater (m)	>1.5		>1.5		>1.5		>1.5		>1.5		>1.5	
Slope (%)	<1		<1		<1		<1		<1		<1	
Rainfall*(mm)	669		602		602		783		1373		786	
Tillage Rating Physical Index	42 0.547		48 0.808		46 0.625		38 0.416		53 0.398		51 0.435	

- Average of 9 soil profiles
- Average of 8 soil profiles
- Average of 4 soil profiles
Ka - Apparent hydraulic conductivity

D = Layer depth (cm); M = Magnitude; * Annual mean () = Values in parenthesis are standard deviations; OM = Organic Carbon; NCP = Non-capillary pore space; AWSC = Available water storage capacity.

RESULTS AND DISCUSSIONS

The tillage rating system (2) was modified to take into account the conditions prevailing in semi-arid and arid tropical regions of India. The soil permeability was replaced by the apparent hydraulic conductivity of the profile; degree of relative compaction was calculated for soil layer having the maximum bulk density in the root zone, with respect to Proctor maximum bulk density of 1.95, 1.85 and 1.75 Mg m^{-3} for loamy sand, silt loam and clay soils, respectively. The ratings of 1,2,3,4 & 5 were used for the relative compaction of <60%, 60-70%, 70-80%, 80-90% and >90%, respectively. The available water storage capacity per meter of solum depth was used for tillage rating. Soil depth was considered directly for the purpose of tillage rating rather than the soil loss tolerance because the root growth varied with the cultivars and the soil water and nutrients reservoir varied with soil depth. In the climatic factors, the annual cumulative erosivity was replaced by the mean annual rainfall having similar ratings of 1,2.3,4 & 5 for the mean annual rainfalls >1150 mm, 750-1150 mm, 500-750 mm, 250-500 mm and <250 mm, respectively, as the annual cumulative erosivity was essentially same for all the soils studied. The probability of conseceutive 7-day rainless period during monsoon season(4) was used instead of 10-day rain-less period due to high evaporative demands for water in semi-arid and arid regions.

The tillage rating varied from 38 for Ustorthent to 53 for Chromustert (MP), and the appropriate tillage systems were minimum tillage/permanent ridges and furrows for Ustorthent; ploughing at the end of the rainy season for Ustipsamment and both primary and secondary tillage for Haplustalf, Chromustert and Ustochrept soils. This tillage rating system(2) did not define the specific requirements of primary and sceondary tillage equipments and the frequency of operations for the user.

Physical Index varied from 0.398 for Chromustert under upland crops in Madhya Pradesh to 0.808 for Chromustert under rice in Tamil Nadu. The physical constraints analysis of these soils carried out by arranging the score of each component of the physical index in ascending order showed that the coarse textured soils, namely Ustipsamment had high Ka, low organic matter and low AWSC; Haplustalf had high bulk density layer at shallow depth; Ustorthent had shallow soil depth, high Ka and low AWSC. The medium textured Ustochrept had high bulk density at shallow depth and very low Ka; the fine textured deep Chromustert under upland crops had high bulk density in subsurface soil, very slow Ka and low NCP; and Chromustert under rice crop had low NCP and low soil strength for support of tillage implements such as puddler.

The appropriate tillage systems for each soil were matched with the specific physical constraints, slope and mean annual rainfall by the use of Table 2. These tillage systems were clay mixing-cum-compaction for Ustipsamment, chiselling for Haplustalf, broad bed and furrows/ridges across the slope/ incorporation of crop residues for Ustorthent, chiselling-cum-crop residue incorporation for Ustochrept, raised beds and sunken beds for Chromustert under upland crops and compaction before puddling for Chromustert under rice crop.

The adoption of matching tillage systems improved the physical conditions of soil and increased the crop yields significantly (Table 3). The clay mixing-cum-Compaction of Ustipsamment increased the grain yields of rainfed pearl millet by 38%, and taramira by 32%; and irrigated wheat by 19% over the control yields of 1.12, 1.09 & 1.94 t/ha, respectively, in Rajasthan. The construction of ridges across the slope on Ustorthent increased the yields of rainfed sorghum grain by 17%, castor seed by 22% and fresh fruit of tomato by 23% over the

Table 2. Matching tillage system to alleviate soil physical constaints.

S. No.	Texture	Soil depth	Bulk density	Ka	AWSC	OM	NCP	Slope	Rain			Tillage systems Upland	Rice
1.	C	D	L	H	O	L	H	<3		~		Cm	CM
2.	C	D	L/O	H	L	L	H	<3	L	M		Cl-cum-Cm	Cl-cum-Cm
3.	C	D	L/O	H	L	L	H	<3			H	Cl-cum-Cm	CR
4.	C	~	H	~	L	L	L	~		~		Ch-cum-CR	Cl-cum-CR
5.	C	~	H	L	O	O	L	~		~		Ch-cum-CR	CR
6.	C	S	O	H	L	L	H	<1	L	M		BBF#	Cm
7.	C	S	O	H	L	L	H	<1			H	Rigdes#	Cm
8.	C	S	O	H	L	L	H	1-3	L	M		BBF/Ridges#	Not suitable$
9.	C	S	O	H	L	L	H	1-3			H	Ridges#	Not suitable$
10.	C	~	O	H	L	L	H	>3		~		Ridges#	Not suitable$
11.	M	~	L	O	~	~	L	<1		M	H	Gypsum & CR	Gypsum
12.	M	~	H	L	O	O	L	~		~		Ch-cum-CR	Ch
13.	M F	~	L	O	~	~	~	<1	L			CR/Mulch	Not suitable$
14.	M F	S	O	L	O	O	L	<1		~		BBF#	
15.	M F	S	O	L	O	O	L	1-3	L			BBF#	
16.	M F	S	O	L	O	O	L	1-3		M	H	Ridges#	
17.	M F	S	O	L	O	O	L	>3		~		Ridges#	
18.	M F	D	H/O	L	H	O	L	<1	L			RBF	
19.	M F	D	H/O	L	H	O	L	<1		M	H	RBSB	Ch-cum-CR
20.	M F	D	O	L	H	O	L	1-3	L			BBF#	
21	M F	D	O	L	H	O	L	1-3		M	H	Ridges#	
22.	M F	D	O	L	H	O	L	>3	L			Ridges#	
23	M F	D	O	L	H	O	L	>3		M	H	Ridges#	
24.	F	~	L	O	~	~	L	<1		M	H	Gypsum/CR	Cm

Cm = Compaction at Proctor moisture by making 8 passes pf 500 kg roller
Cl = Clay mixing @(1-2)% as fine texture soil
Ch = Chiselling once in tractor width up to 0.4 m
CR = Crop residue incorporated @ 5 t/ha
$ = Not suitable unless terraces are constructed
Ka, AWSC, NCP & OM refor to Table 1.

C = Coarse, F = Fine, M = Medium, ~ Any value, D = Deep & medium deep, S = Shallow soil, H = High, O = Optimum, L = Low, F = Furrows, # = Across the slope, ## = Along the slope, ### = Ridges across the slope with interception ridges/barriers at 10 meter intervals, BB = Broad beds, RB = Raised beds, SB = Sunken beds.

control yields of 1.73, 1.61 and 16.90 t/ha, respectively, and incorporation of rice husk @ 5 t/ha increased the yield of castor seed by 25% over 1.88 t/ha in Andhra Pradesh. Chisel ploughing of Haplustalf up to 35 cm depth at 100 cm intervals increased the grain yield of rainfed sorghum by 27%, maize by 56%, black gram by 64%, the pod yield of groundnut by 29% and fresh fruit yield of tomato by 27% and yield of irrigated sorghum grain by 40% and tapioca tuber by 22% over the control yields of 1.35, 2.10, 0.36, 1.53, 2.53, 3.00 and 4.40 t/ha in Tamil Nadu. The chiselling up to 40 cm depth at 100 cm intervals along with the incorporation of rice husk @ 10 t/ha in Ustrochrept increased the grain yield of irrigated wheat hy 12% over the control yield of 3.42 t/ha in Punjab. The construction of raised beds and sunken beds on Chromustert increased the grain yields of rainfed soybean by more than 2 fold, black gram by 7 fold and sorghum by 17% over the control yields of 0.98, 0.13 and 13.6 t/ha in Madhya Pradesh. The compaction of fluffy Chromustert increased the soil strength for movement of tillage implements including puddler for field operations and increased the yield of rice grain by 41% over the control yield of 4.47 t/ha in Tamil Nadu.

Table 3. Effect of improved tillage practices for different soils on rainfed crop yields (t/ha)###

Soils	Crops and yields			
Ustipsamment (Rajasthan)		Pearlmillet (BJ-104) (1.12)1.55*	Taramire (RJM-2) (1.09)1.44*	Wheat# (Kalyansona) (1.94)2.31*
Ustorthent (Andhra Pradesh)	Sorghum (CSH-5) (1.73)2.03*		Castor (Aruna)-S (1.61)1.97* (1.88)2.35*##	Tomato FF (16.90)20.62*
Haplustalf (Tamil Nadu)	Sorghum# (CSH-5) (1.35)1.72* (3.00)4.20*#	Maize Ganga-5) (2.10)3.27**	Blackgram (T-9) (0.36)0.59*	Tomato FF (2.53)3.22*
		Tapioca# (H-1687)-T (4.40)5.38*	Groundnut (POL-1)-P (1.53)1.97**	
Ustochrept (Punjab)				Wheat# (WL-711) (3.42)3.82*
Chromustert (Madhya Pradesh)	Sorghum (CS-3541) (1.36)1.59*	Soybean (JS-2) (0.98)2.31**	Blackgram (T-9) (0.31)0.99**	
Chromustert (Tamil Nadu)				Rice# (Paiyura) (4.47)6.29*

#Irrigated, ## Incorporation of rice husk @ 5 t/ha,
Grain yield except where indicated by P=Pod, FF=Fresh fruit weight. S=Seed. T=Tuber. ()=Values in parenthesis are the crop yields under farmers level of management. * Significant at 5% level. ** Significant at 1% level.

CONCLUSIONS

The tillage index calculated hy the use of modified rating system varied from 38 for Ustorthent in Rajasthan to 53 for Chromustert in Madhya Pradesh. The Physical index varied from 0.39 for Chromustert under uplands in Madhya Pradesh to 0.808 for Chromustert under rice in Tamil Nadu. The adoption of matching tillage systems based on specific soil physical constraint, slope and mean annual rainfall increased significantly the yields of different crops under actual practical farming conditions.

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Effects of soil compaction on N-mineralization and microbial C and N: Field measurements and laboratory simulation.

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ABSTRACT.

Effects of soil compaction on net nitrogen mineralization and microbial biomass dynamics were studied both in the field and in a laboratory simulation experiment. Soils were silty clay loams in either a permanent pasture or a long term cropped site. In the field study, compaction treatments were applied by five passes of a tractor. Soil dry bulk densities increased significantly only in the permanent pasture site. However, soil surface CO_2-flux rates decreased substantially after compaction on both sites, possibly because of highly reduced air permeability caused by deformation of the topsoil. Oxygen diffusion rates changed significantly following compaction only at the 28 y cropped site. Net nitrogen mineralization measurements by the *in situ* core technique were found to be problematic as denitrification losses possibly occurred. Microbial biomass did not decrease significantly over time as a result of the compaction treatment. In the laboratory experiment, soils from the two sites were compacted into cores at different bulk densities and equilibrated to different soil water potentials before incubating at 25°C for 21 d. Carbon mineralization was positively correlated with soil moisture levels. Net nitrogen mineralization showed a similar pattern only for well aerated, low density permanent pasture cores. Microbial biomass estimates decreased from the initial level during incubation if measured by fumigation-extraction, particularly in the samples with high moisture, but increased, and were relatively unaffected by moisture, if measured by the substrate-induced respiration method.

INTRODUCTION.

On heavier-textured soils, compaction can be a major limitation to crop production (1). In such soils the resistance to compaction is particularly influenced by the strength and proportion of soil macro-aggregates (2). The proportion of stable macro-aggregates decreases when native soils or permanent pastures are cultivated (3), because of a marked decline in organic carbon content and microbial biomass as well as mechanical disturbance. The microbial biomass in soil has a rapid turnover and thus plays a major role in nutrient transformations. The loss of nitrogen via denitrification is also known to increase upon compaction (4,5) but the effect of soil compaction on mineralization-immobilization turnover has to date been addressed by only a few authors (6,7,8,9). The objectives of this study were to:

a) Assess the effects of soil compaction in the field on physical properties, net nitrogen mineralization, and microbial biomass and activity in two similar soils of different cropping histories.
b) Assess the changes in turnover of nitrogen and microbial biomass caused by soil compaction and different soil moisture levels under laboratory simulation of field conditions with the same two soils as in a).

MATERIALS AND METHODS

Soils were Typic Endoaquepts (with a topsoil of silty clay loam, clay 36%, silt 58%, sand 6%) of the Manawatu district, New Zealand from a field cropped continuously with cereals for 28 years using conventional tillage (2.1%C) and from a permanent pasture (4.6%C). Further details of these soils can be found in (2).

Field experiment: Compaction treatments were carried out with five passes of a tractor (4,880 kg. total weight) at field moisture contents close to the optimum water content for compaction. Soil bulk densities before and after the compaction treatment were estimated from cores (60 mm diameter) taken in 10 cm depth segments. Mean effective pore diameters, and hence pore size distribution, were calculated from the water potential - moisture relation according to (10). Air permeability was measured on the cores using a flow-rate air permeameter. Basal soil respiration was measured as CO_2-flux rate from the soil surface immediately after compaction in both compacted and non-compacted areas using the static chamber technique with ten replicate field respirometers (11). Oxygen-diffusion rates (O.D.R.) were measured concurrently using ten replicate platinum O.D.R. electrodes (12) inserted to depths of 5 and 10 cm respectively. Nitrogen mineralization was measured using an *in situ* method (13) with eight replicate cores per treatment, inserted into 15 cm depth and covered to avoid leaching. The cores were incubated in the field for two subsequent incubation periods (28+28 d at the 28 y cropped and 21+21 d at the permanent pasture site).

Laboratory experiment: Moist and coarsely sieved (< 5.6 mm) 0-15 cm soil from both of the above sites was compacted into 60 mm (d) x 25 mm (h) cores by miniature Proctor compaction (14) to two different bulk densities, viz. *Low density* (1.07 and 0.88 t m^{-3} for the 28 y cropped and the permanent pasture soils respectively) resembling a cultivated situation and *High density* (1.30 and 1.15 t m^{-3} for the 28 y cropped and the permanent pasture soils respectively) resembling the compacted field density. The water contents of the cores were adjusted on tension plates to -1, -5, -10 and -100 kPa, and the pore size distribution etc. was calculated as above. Water-filled pore space (WFPS, %) was calculated as *Volume of soil water * 100 / Total pore volume* (15). Air permeability of the cores was determined as above. The cores were incubated at 25°C for 21 days and net N-mineralization was estimated from the increase in inorganic-N, C-mineralization was measured by absorption of the evolved CO_2 in alkali.

Analysis: Before analysis, soils were sieved (< 5.6 mm). Inorganic-N was measured using colorimetric AutoAnalyzer methods. Microbial biomass was estimated using both the fumigation-extraction method (FE) (16) with a K_{EC} of 0.33 and the modified substrate-induced respiration method (SIR) (17) calculating biomass C ($\mu g\ g^{-1}$ soil) as 50*SIR ($\mu l\ CO_2\ g^{-1}\ h^{-1}$).

RESULTS AND DISCUSSION

Field experiment: The mean dry bulk density in 0-10 cm depth in the field did not increase significantly upon the compaction treatment in the 28 y cropped site (Table 1). This was probably due to the relatively high initial density and a severely degraded physical structure even before the compaction treatment as a result of many years of continuous cereal cropping with an inappropriate soil tillage practice. However, in the less dense permanent pasture soil the bulk density increased significantly ($P<0.001$). The CO_2-flux from the soil surface following compaction was substantially lowered (by 57-69 % relative to non-compacted soil, $P<0.001$, Table 1) in both soils. This was accompanied by a large decrease in the air permeability of the 0-10 cm layer ($P<0.05$, Table 1). However, oxygen-diffusion rates at 5 and 10 cm depth decreased significantly following compaction treatment only in the 28 y cropped site ($P<0.05$, Table 1). The compaction treatment reduced mainly the intermediate (3-30 μm) and micro (0.2-3 μm) pores (Figure 1a), and the compaction energy input to the soil seems to have resulted in a

Table 1 Mean values of dry bulk density, CO_2 -flux rate, O_2-diffusion rate, air permeability and microbial biomass C (estimated by either the FE or the SIR method) for 28 y cropped and permanent pasture soils with and without field compaction. Means ± SE (dry bulk density and air perm. n=6, SIR n=4, FE n=3 and others n=10). ND = Not determined.

Parameter:		28 y cropped Noncompacted	28 y cropped Compacted	Perm. pasture Noncompacted	Perm. pasture Compacted
Dry bulk density (t m^{-3}), 0-10 cm		1.30 ± 0.02	1.34 ± 0.02	1.00 ± 0.03	1.17 ± 0.01
CO_2-flux rate (mg C m^{-2} h^{-1})		60 ± 7	19 ± 1	148 ± 11	64 ± 4
O_2 diffusion rate	at 5 cm	17 ± 3	9 ± 2	36 ± 3	31 ± 3
(10^{-8} g O_2 cm^{-2} min^{-1})	at 10 cm	19 ± 9	11 ± 2	35 ± 2	35 ± 3
Air permeability[a] (10^{-11} m^2) 0-10 cm		3.5 ± 1.6	0.25 ± 0.07	1.1 ± 0.4	0.02 ± 0.06
FE Biomass C	Start incub.	328 ± 24	ND	807 ± 14	ND
(μg g^{-1} soil)	End incub.[b]	340 ± 44	421 ± 48	841 ± 23	862 ± 23
SIR Biomass C	Start incub.	387 ± 24	ND	696 ± 33	ND
(μg g^{-1} soil)	End incub.[b]	316 ± 8	309 ± 14	618 ± 25	691 ± 11

[a] Air permeability values > $4x10^{-11}$ m^2 are considered to be non-limiting to plant growth, while values < $0.1x10^{-11}$ m^2 are considered to be completely limiting to plant growth (B. Kroesbergen, pers. comm.)

[b] After incubating in the field for either 42 days (28 y cropped) or 56 days (permanent pasture).

deformation of the topsoil with some redistribution of pore space to smaller pore size classes at both sites. The large decrease in CO_2-flux from the surface of the compacted areas was probably caused by the reduction in air permeability and not by substrate or oxygen limitations to the respiration, because the oxygen diffusion rates did not change in the permanent pasture after compaction. Inorganic nitrogen content of covered *in situ* cores (Figure 2) at the 28 y cropped site showed no significant differences between treatments. However, denitrification losses from the covered cores may have occurred as there was a decrease in inorganic-N content between days 28 and 56, where wet conditions prevailed. In the permanent pasture, the apparent net N-mineralization rates were significantly lower in the compacted treatment between days 21 and 42 ($p<0.01$), but whether this was due to lower mineralization or increased denitrification cannot be determined. The inherent problems of the *in situ* technique have previously been discussed elsewhere (18,19). With this particular soil type, and under the prevailing weather conditions of high rainfall, the technique proved to be problematic because negative apparent net N mineralization rates were determined at both sites. Microbial biomass C decreased significantly from the initial level, but did not differ significantly between compaction treatments in the 28 y cropped site, whereas it decreased significantly only in the noncompacted area of the permanent pasture site.

Laboratory experiment: When compacted to the low density the coarsely sieved soils used in the laboratory experiment had a much larger proportion of macro pores (> 60 μm, Figure 1b) than the soils in their natural state in the field (Figure 1a). The high compaction treatments in the laboratory experiment mainly decreased the proportion of these macro pores, while coarse, intermediate and micro pores (30-60, 3-30 and 1-3 μm respectively) remained unchanged. Therefore, the related change in bulk density would not have affected the microbes or their grazing by the micro-fauna directly (8). However, the changes in water-filled pore spaces (WFPS %) and air permeability (Figure 3) would be expected to have had a great impact on microbial activity (9,15). Carbon mineralization at 25°C was generally positively correlated with soil moisture levels (Figure 3). Net nitrogen mineralization showed a similar pattern only for the well aerated, low density permanent pasture cores with a C:N-mineralization ratio of approximately 25 (Figure 3).

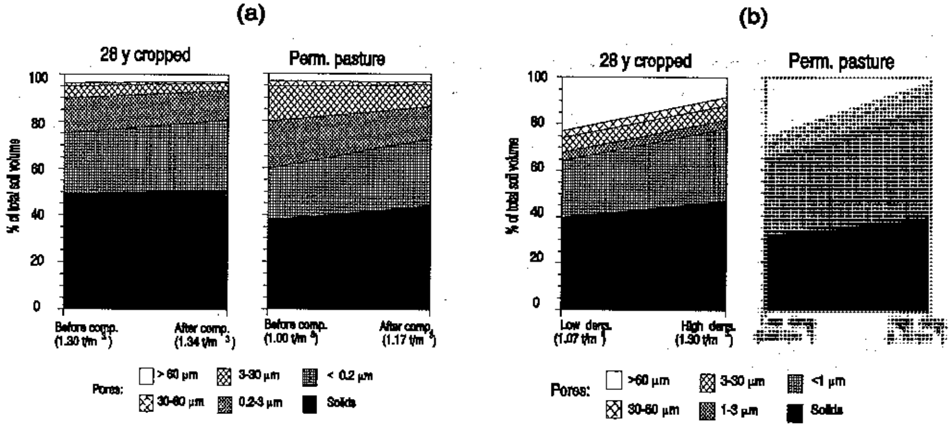

Figure 1. Pore size distribution as percent of total soil volume for different dry bulk densities in (a) the field experiment and (b) the laboratory experiment.

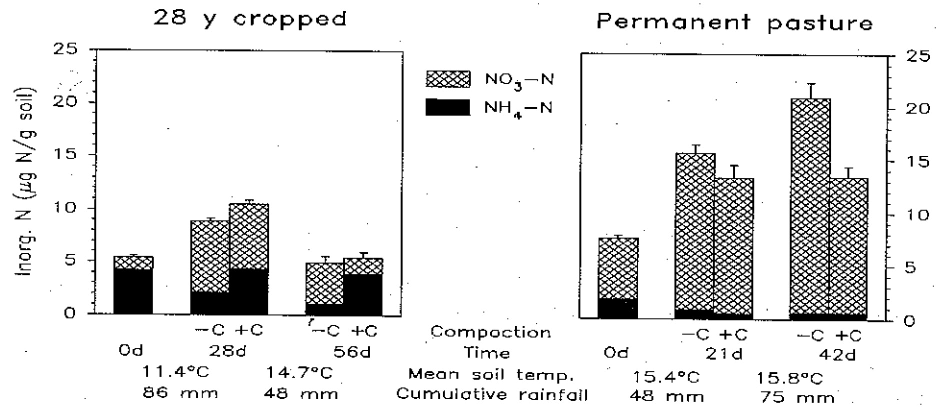

Figure 2 Inorganic-N content of *in situ* cores as a function of incubation time and compaction tratment (+C:compacted, -C:noncompacted). Bars indicate SE (n=8).

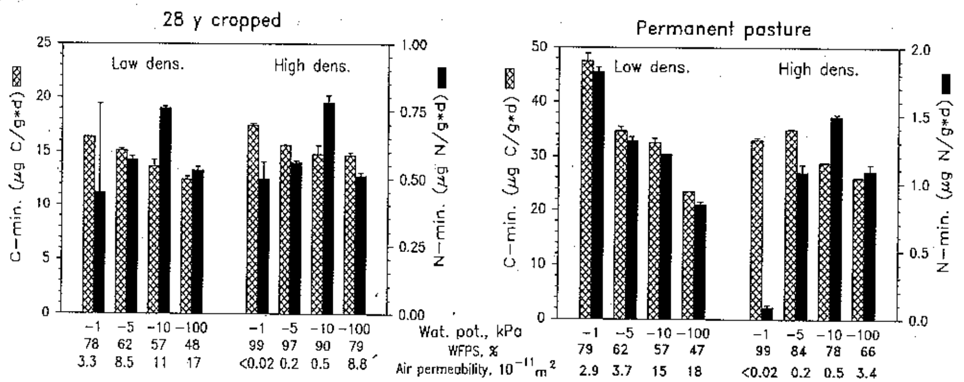

Figure 3. C and N mineralization rates as affected by soil water potential, WFPS, air permeability and bulk density. Densities: Low=1.07 and 0.88 and High=1.30 and 1.15 t m^{-3} for 28 y cropped and permanent pasture. Bars: SE (n=2).

In most of the other cores, apparent net N mineralization rates showed different patterns from those of C mineralization, with maximum rates occuring at -10 kPa. The apparent net N mineralization rate in the high density, permanent pasture cores at -1 kPa was very low, possibly because of increases in denitrification activity (4,5). It is surprising however, that the N mineralization patterns of the low and high density 28 y cropped soil did not differ more, as there were very large difference in air permeabilities between the two density treatments. Although it was coarsely sieved, the 28 y cropped soil may still have retained some relatively dense aggregates smaller than 5.6 mm in which partly anaerobic conditions could have prevailed at a high moisture content, in spite of the relatively high air permeability of the whole soil core. However, these explanations remain speculative as no confirmation measurements have been performed. The microbial biomass C levels following compaction and incubation seemed to decrease if measured by FE ($P<0.01$, Table 2), particularly in the samples with a high moisture content, but to increase significantly following compaction and incubation ($P<0.05$ for 28 y cropped soil and $P<0.01$ for permanent pasture, Table 2) if determined by SIR. SIR biomass C seemed generally unaffected by density and moisture in the 28 y cropped soil, whereas it was slightly lowered by high density in the perm. pasture soil ($P < 0.05$). It is surprising that the microbial biomass C estimates by the FE and the SIR methods differed so substantially. However, decreases in microbial biomass, as estimated by FE, with increasing soil compaction were also found by (8). Both their and the current experiment were conducted at higher-than-normal field temperatures and this might explain why the microbial biomass decreased in the laboratory and not in the field experiment. The SIR method has by some authors (20, 21, 22) been interpreted more as a measure of active than total microbial biomass. In the present study it is possible that this increased SIR response of the compacted and incubated samples is indicative of changes in population structure and metabolic activity of the microbial community under the high moisture conditions. However, without more detailed studies into physiological effects on the microbial biomass, no final conclusions about the differences in FE and SIR biomass C estimates can be made.

Both the field and the laboratory experiments were useful for indicating both physical and biochemical differences between the sites. Both experiments also indicated that N-mineralization and the turnover of microbial biomass was not affected directly by compaction, but rather indirectly via the effects on soil aeration. Therefore it is important to quantify denitrification losses when studying nitrogen turnover in compacted soils. Denitrification losses were successfully quantified in a similar laboratory study (5) by calculating a mass balance of applied ^{15}N-labelled NH_4NO_3. This approach could possibly also be applied in future field studies with the *in situ* coring method.

Table 2 Microbial biomass C (estimated by either the FE or the SIR method) as affected by bulk density and 3 of the water potentials during 21 d incubation at 25°C. Means ± SE. (SIR n=4, FE n=3).

	Biomass C, µg g-1 soil					
	28 y cropped			Permanent pasture		
Wat. pot. kPa	Bulk.dens. t m^{-3}	SIR	FE	Bulk.dens. t m^{-3}	SIR	FE
Initial[a]	-	244 ± 18	414 ± 57	-	534 ± 14	1202 ± 30
-1	1.07	369 ± 20	151 ± 21	0.88	837 ± 25	507 ± 6
-10		316 ± 11	177 ± 10		861 ± 43	601 ± 10
-100		357 ± 22	315 ± 13		858 ± 21	1021 ± 14
-1	1.30	291 ± 20	198 ± 22	1.15	733 ± 24	52 ± 6
-10		352 ± 14	192 ± 31		743 ± 21	632 ± 35
-100		384 ± 12	342 ± 19		762 ± 12	721 ± 39

[a] Initial values measured before soils were compacted and adjusted for moisture content

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THE EFFECTS OF TILLAGE ON SOILS OF THE WEIJA IRRIGATION PROJECT IN GHANA

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ABSTRACT

The supply of adequate amounts of vegetables to the Accra-Tema metropolis has been the main objective of the Weija Irrigation Company (WEICO). The above objective has not been achieved in its entirety, partly because of factors such as poor water management and unreliable drainage systems. This paper reports results of studies on compaction of the soils monitored on 3 different plots, ie. uncultivated plot (U), developed and cultivated plot but abandoned for the past 3 years (DU) and developed and continuously cultivated plot (DC). The textures of the 3 plots are loamy sand, sandy clay loam and sandy loam for U, DU and DC respectively. Bulk densities for the test plots were in the range of 1450-1870 kg/m^3. Higher soil resistances and bulk densities occured on DC at depths of 15-25cm, suggesting compaction at plough sole depth. Proper irrigation water management, incorporation of organic matter into the soil, drainage by a series of beddings within unit plots, sub-soiling and the reduction of vehicular traffic are sugested as short term solutions to ameliorate production problems and to improve workability.

INTRODUCTION

Serious irrigation practice in Ghana dates back to the late 1950's after independence. This was neccesitated by the erratic and unreliable rainfall during the critical growth periods of most crops. The total irrigated land stood at 7500 ha, a mere 0.03% of the total land area in 1990 (MOFA, 1991), spread in all the agro-ecological zones of the country. The coastal and northern savannah belts register the highest concentration of irrigated fields with rice as the single most important crop, others being maize, sugarcane and vegetables. The Weija Irrigation Project (WIP) is located in the coastal savannah zone, close to Accra, the capital city of Ghana. It extends over an area of 1700 ha in two distinct land areas separated by a distance of 7.5 km but have the Weija impounded reservoir as the common water source (IDA, 1976).

Sprinkler irrigation is practised and it specialises in the cultivation of vegetables to feed the teeming population in the capital and its environs. Performance indicators for the past decade or thereabout have not been encouraging despite the provision of capital, reasonable logistic support and the use of improved cultural practices. Farmers complain of persistent weed growth and declining yields. Waterlogging on the fields impair workability and drains placed at the peripheries of unit plots are in need of repairs. Water management is mainly by experience. Farmers who get saddled with debts abandon their farms leaving behind huge unsettled rent and irrigation charges. This means net returns in terms of revenue is not realised by WEICO. Presently a maximum 220 ha of the larger area is cropped annually but most often, this target is not achieved leading to gross underutilization of the project.

It is the declining yields problem and the need to investigate the causes, that forms the main objective of the study. Specifically, the study sought to monitor the effect of compaction on soils on three representative plots.

MATERIALS AND METHODS

Compaction studies involved observing the soil profile and taking soil samples on plots 73, 82 and 87 (see fig. 4) which were chosen for the study in June, 1992 during the major cropping season to allow for possible tillage induced treatments on the project. Plot 73 (U) had remained uncultivated for over 5 years, plot 82 (DC) had been developed and cultivated continuously and plot 87 (DU) on the other hand had been developed and cultivated for sometime but abandoned for the past 3 years. Each plot of size 200m x 100m was grided into 8 parts and samples taken at the mid-point of each grid. 56 samples at 7 samples per grid were taken at 5cm depth increments to 35cm, for bulk density and moisture content analysis and 8 bulk samples were taken for particle size and pH determination.

Measurement of soil strength and mechanical impedance to root penetration were taken with a hand operated Eijelkamp 74 penetrometer. Readings were taken at 5cm depth intervals to provide adequate resolution in measurement to allow for discrimination of tillage induced changes in the soil within the "tillage zone" of up to about 35cm. Particle size analysis was by the Bouyoucous hydrometer method. Moisture and bulk density measurements were by the gravimetric method at 105°C for 24 hours, pH determination was by analogue pH meter on 1/1 water extracts and 0.1N KCL solution.

RESULTS AND DISCUSSIONS

From the particle size analysis, sand fraction ranged from 67-83%, silt 9-15% and clay 9-19%. The preponderance of sand particles over the other soil fractions were evident and therefore, there was the expectation of a well-drained soil and yet waterlogging seemed prevalent. It was, however, observed that deep down within the profile fractions of clay which tended to impede percolation were present. This is the result of over-application of water and the effect of intense tropical storms causing eluviation and poor drainage. Waterlogging creates anaerobic conditions which affects root respiration and leads to toxic concentrations of carbon dioxide thereby lowering yield.

Tillage operations had a significant effect on bulk density, measured soil impedance and moisture content at plough sole. Figure 3 shows bulk density profiles for each soil tillage type. Changes in bulk density with depths were characteristic of the particular tillage system and were apparent in the upper 25cm depth of the soil profile. Actual bulk density figures ranged from a minimum of 1450 kg/m^3 for DU and a maximum of 1850 kg/m^3 for DC at depths of 15-25cm (see fig. 3) suggesting compaction at plough sole depth. This is further reinforced by the soil impedance values at the same depth in fig. 2. Higher bulk density affects root penetration which is likely to keep nutrients beyond the reach of plant roots.

Maximum soil impedance values ranged between 2.65-2.90 MPa for DC at depths of about 15-25cm corresponding to the high bulk density and moisture content zones. Soil impedance values for DU and U ranged from 2.80-3.00 MPa and 1.90-2.00 MPa respectively. On the whole, impedance and bulk density values are lowest for U, DU being intermediate and DC being the highest. Linear contrast comparison of bulk densities between the different plots across almost all depths of tillage showed no significant interaction with depth. The contrast in best fit resulted from the greatest values in the 15-25cm depth range. The difference may have occured as a consequence of tillage operations during wet conditions when soil is more susceptible to compaction.

Soil moisture content as presented in fig. 1 show that water content in the surface 25cm depths of U and DU are nearly similar but less than that of DC at each depth. Higher moisture content occurred on DC at depths below 15cm suggesting higher porosity. The pH values measured on 0.1N KCl solution were 0.5-1.0 lower than those measured on water. Since pH values are less affected by seasonal changes when measured on 0.1N KCl solution, these values tend to be reliable, and pH of DC ranged from 6.2-8.0 while that of DU and U ranged from 5.4-7.1. Therefore DC showed slight alkalinity and the others slight acidity.

CONCLUSIONS

Since all the soils have higher fractions of sand, it means that water holding capacity is low. This could be improved by the incorporation of organic matter by ploughing in plant residue and cow dung which is available in nearby villages and burning should be discouraged. Higher impedance values on DC will definitely affect root development and consequently yield. Higher bulk density and impedance layers at 15-25cm depth could be ripped with chisel ploughs and by reducing the number of passes by farm equipments on the field. Existing drains must be rehabilitated and ditch drains or some series of beddings within farm units can help offset inundation problems. Very good water management is essential to prevent over-application of water which causes eluviation which in turn slows down percolation. Installation of simple soil moisture measuring devices, especially, tensiometers (since soils are mainly sandy) and some training in water management for farmers and management alike will help limit the tendency to overapply water and also cut down on the operational cost of the pumps.

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APPENDIX

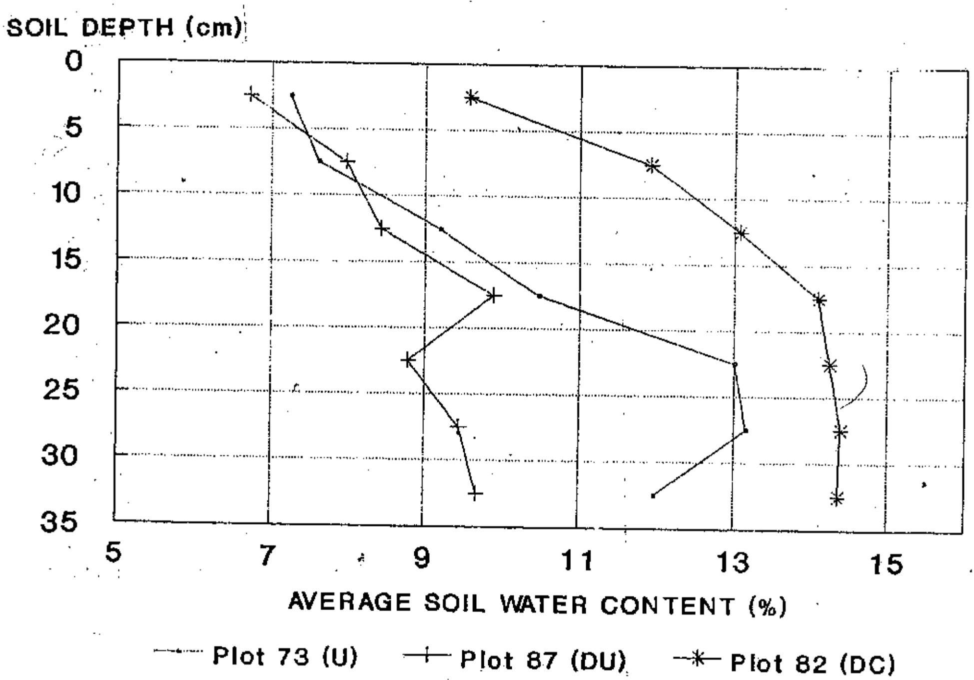

Fig. 1 Water content by depth within each tillage treatment at time of Soil Impedance measurements

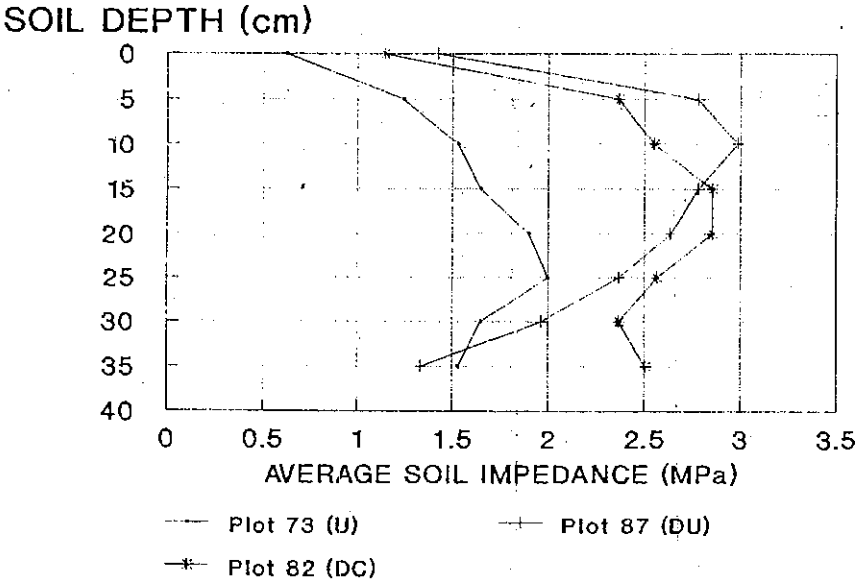

Fig. 2 Variation of Soil IMpedance with Depth as a function of Continuous Tillage

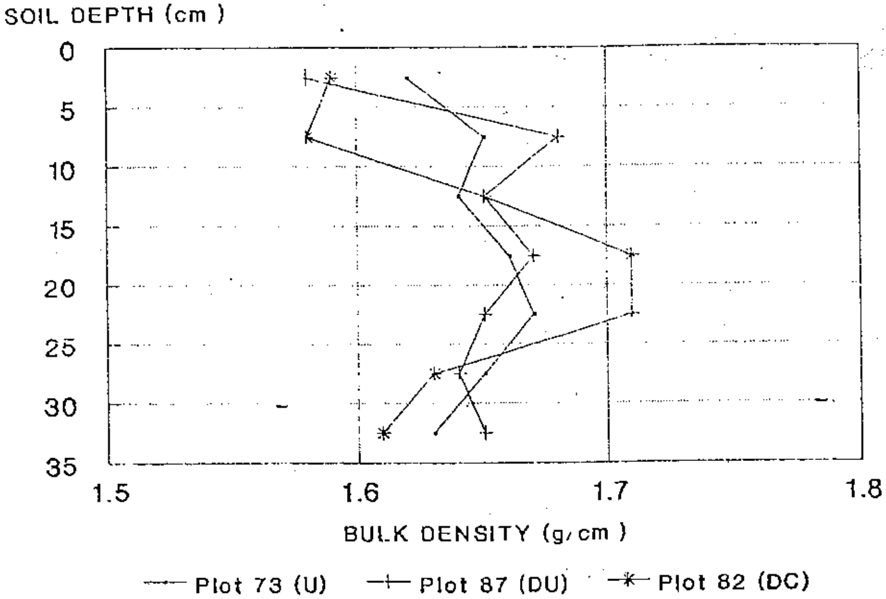

Fig. 3 Variation of bulk density with depth as a function of continuous tillage

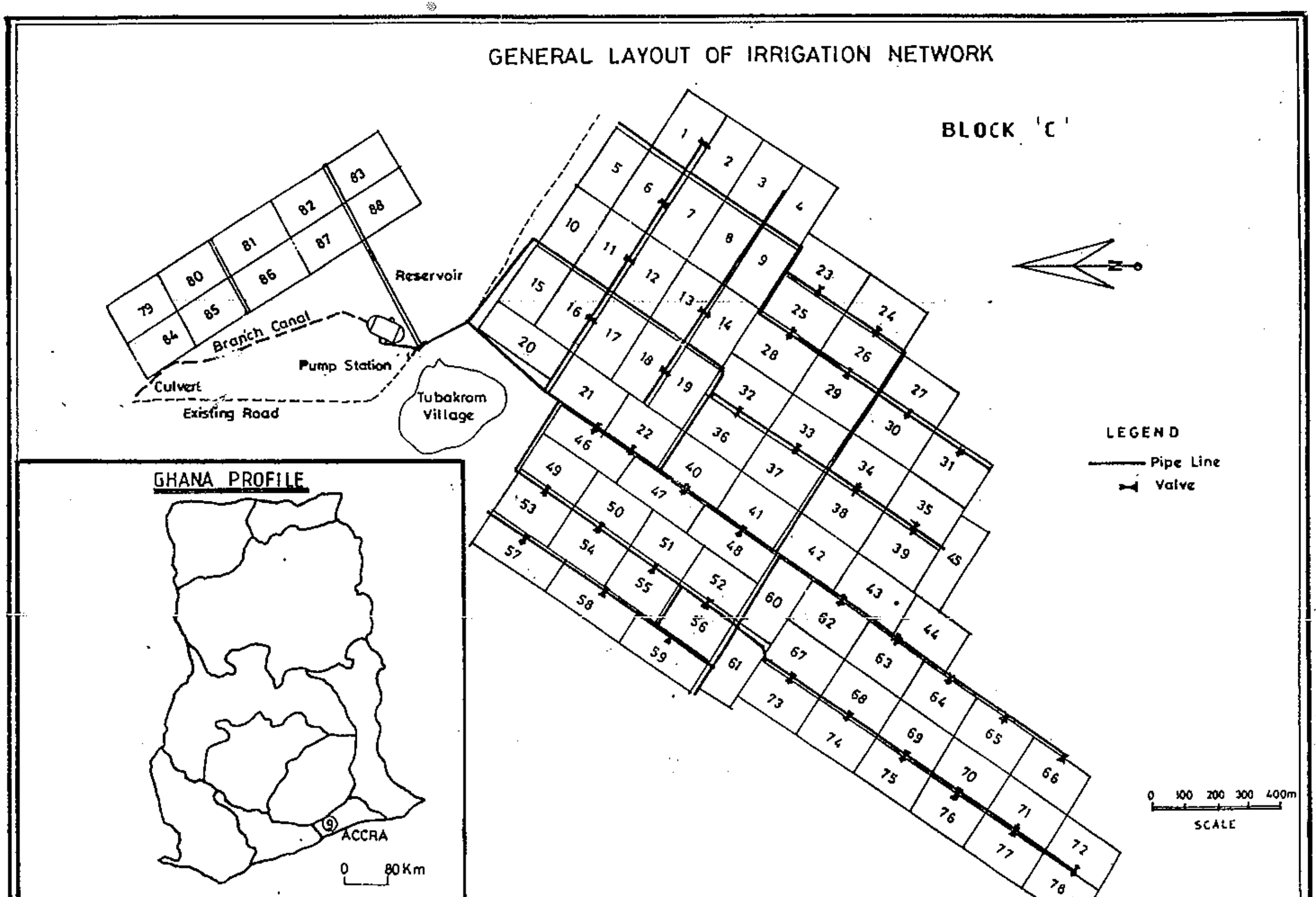

FIG. 4 GHANA PROFILE SHOWING LOCATION OF WEIJA IRRIGATION PROJECT

EFFECTS OF PERENNIAL FORAGE SPECIES INTERCROPPED WITH SILAGE CORN ON SOIL QUALITY IN EASTERN QUEBEC.

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ABSTRACT

Silage corn monocnlture on dairy farms is conductive to soil degradation, mainly by erosion, compaction and loss of productivity. On the counterpart long term meadow has beneficial effects on soil quality. An ongoing field experiment was initiated 7 years ago, on a silt loam, to study a new cropping system comhining both crops in a two years rotation, one year corn intercropped with a perennial forage species followed by one year hay meadow. Five different forage species were seeded at the same day as corn on all the area between corn rows, every two years. These perennial species intercropped with corn became the meadow the following year. Tillage performed only the corn year included spring plowing at 15 cm, compaction rolling, disc harrowing and field cultivation prior to planting. Soil organic C, permeability, porosity and water-stable aggregation were measured every second year after the last hay cut. Hydraulic conductivity, total porosity and air-filled porosity remained unchanged during the six year period. Water-stable aggregation improved regularly after 4 and 6 years with the intercropped species, particularly with legumes species. Aggregate mean-weight diameter (MWD) was the most sensitive parameter for soil quality evaluation.

INTRODUCTION

A recent survey of the problems of soil degradation in agricultural soils of Québec has shown that soil structure, porosity and organic matter content and to some extent erosion, were affected by cereals and corn monoculture as compared to soil under perennial forages (1). One of the recommendations from this survey report is to use crop rotation including perennial forages species. On many dairy farms long duration rotations (1 or 2 years annual crops followed by 4 to 5 years hay) have been replaced by silage corn or grain cereal monoculture in some particular fields while the rest of the farm is cropped with the usual rotation. Intercropping red clover with silage corn, on a monoculture basis, can also effectively control soil erosion and runoff, without reducing silage corn yields (2). On commercial grain corn and cereal farms, hay (meadow) could be reintroduced in the rotation since there is a potential lucrative market for hay. Research on shorter crop rotations (1 year corn or grain cereal intercropped with perennial forages species, followed by only 1 year hay), have shown high productivity for these particular cropping systems (3, 4). Soil quality parameters could explain part of this productivity increase. It is defined as the ability of the soil to perform three critical functions: i) provide a medium for plant growth, ii) regulate and partition water and gas flow through the environment and iii) serve as an effective environmental buffer (5).

The present paper reports on the effects of a 2 year rotation system (5 perennial forage species intercropped with silage corn the first year, followed by hay the second year), on soil organic carbon content, permeability, porosity and water-stable aggregation, over a 6 year period.

MATERIALS AND METHODS

A field experiment was initiated in 1987, on a poorly-drained Le Bras soil series (Gleyed Humo-Ferric Podzol), located 30 kilometres south of Quebec City, Canada. The experimental site is tile drained. The particle size distribution of the tilled layer (0-15 cm) at the site is 36% sand, 43% silt and 22% clay. The experimental design is a randomized complete bloc repeated 3 times, where the 6 treatments are the 5 different perennial forage species intercropped with corn and a control (corn without intercropping). The forage species were: timothy and bromegrass as grass species, alfalfa and red clover as legume species and finally a mix of red and white clover and timothy which is a commonly used hay mix in Québec for long term meadow. While the usual way of establishing a meadow on dairy farms in Quebec is by intercropping forage species with small grain cereals, in our experiment corn replaced the cereal. The seeding rates for the forage species were respectively 10 kg/ha for red clover and for timothy, 12 kg/ha for alfalfa, 15 kg/ha for bromegrass and 17 kg/ha for the mix species.

Corn was grown each years in the control plots. In intercropped plots, corn was grown in 1987, 1989 and 1991. The forage species intercropped with corn were cultivated as a meadow the following year (1988, 1990, 1992).

The field has been occupied by a grass meadow for four years before commencing the experiment. This grass meadow was moldboard-plowed in spring 1987 at a 15 cm depth, before corn planting. Secondary tillage, the day after plowing included 1 pass of roller packer, 1 pass of disc harrow and 1 pass of spring tooth harrow (5 cm deep), to incorporate fertilizers and prepare the seedbed. Corn planting was done with a 4 row planter, while forage species were seeded, the same day as corn, with a roller equipped mounted grass seeder, perpendicular to corn rows. The same tillage and seeding procedures were followed in 1989 and 1991 to prepare the seedbed on all the plots. Chisel plow replaced the moldboard plow on control plots in 1988, 1990 and 1992. Corn and hay silage were harvested with regular size farm machinery. Three cuts of silage hay were taken per year.

Soil sampling in late fall, after the last cut of hay, in each plots, was repeated in 1988, 1990 and 1992, at two depths, 0-7 cm, 8-15 cm. Core samples (7.5 cm diameter, 7 cm hight) and block samples were randomly taken at two locations in each plots. The blocks (7 cm x 7 cm) were taken with a spade and kept in plastic jars. All the samples were kept at 5^0C until analysis. Saturated hydraulic conductivity (15 cm constant head lab permeameter), total porosity and 5 kPa and 10 kPa air-filled porosity were measured on cores samples. The soil from the blocks was broken by hand then passed through an 8 mm sieve. Organic carbon, was measured by wet oxidation on whole soil. The size distribution of water-stable aggregates was measured on 50 g of field-moist soil (<8 mm) and (5-8 mm) diameter soil particles, using a nest of the following sieves: (5, 2, 1, and 0.2 mm openings). Wet sieving was performed and a correction was made for sand using Kemper and Chepil method (6). Aggregate mean-weight diameter (MWD) was then calculated.

All the soil parameters were statistically compared using the same following contrasts: Control vs all species; legumes vs non-legumes; timothy vs bromegrass; clover vs alfalfa; mix species vs control. Only statistically significative contrasts are presented.

RESULTS AND DISCUSSION

Soil structure

The first two years of corn monoculture under intensive tillage (control plots), did not show any decrease of MWD compared to intercropped corn. Stable soil structure inherited from previous grass meadow is probably responsible for this. The effects of the intercropped treatments were seen first in the upper part of the tilled layer after four years, than in the lower part after six years. The legume species intercropped with corn had a positive effect on MWD, more rapidly (after 4 years) than the grass species (only after 6 years), in the upper part of the tilled layer. The legumes species were also the first one, after six years, to have a positive effect on MWD in the lower part of the tilled layer (Table 1). From (Table 2) it can be seen that when the whole soil is considered, the effects of intercropped species on MWD is delayed to the sixth year. Water-stable aggregates >5 mm were mostly responsible for the effects on MWD (data not shown).

Table 1. Effects of 2, 4 and 6 years of intercropping, on MWD of water-stable aggregates, measured on (5-8 mm diam.) soil particles.

Time (year)	2		4		6	
Depth (cm)	0-7	8-15	0-7	8-15	0-7	8-15
	---------- MWD (mm) ----------					
Timothy	1.81	2.05	1.66	1.92	4.04	3.66
Bromegrass	2.11	2.37	1.49	1.88	3.70	3.70
Timothy-clover mix	1.57	3.14	2.28	2.01	3.14	3.72
Clover	2.00	2.31	2.67	2.19	3.31	3.96
Alfalfa	2.37	2.40	2.14	2.15	3.65	4.00
Control	1.70	2.25	1.32	1.63	1.80	3.74
Soil moisture (%)	28	26	26	24	28	27
SIGNIFICATIVE CONTRASTS	(*: P < 0.05; --: non significative)					
Control vs all species	--	--	--	--	*	--
Legumes vs grass	--	--	*	--	--	*

Table 2. **Effects of 4 and 6 years of intercropping, on MWD of water-stable aggregates, measured on (0-8 mm diam.) soil particles.**

Time (year)	4		6	
Depth (cm)	0-7	8-15	0-7	8-15
	------------ MWD (mm) -----------			
Timothy	0.79	1.16	2.43	1.82
Bromegrass	0.93	1.38	2.01	1.95
Timothy-clover mix	1.24	1.60	1.84	1.87
Clover	1.50	1.72	2.00	2.12
Alfalfa	1.21	1.79	1.95	2.35
Control	1.13	1.32	1.37	2.07
Soil moisture (%)	26	24	28	27
SIGNIFICATIVE CONTRASTS	(*: P < 0.05; --: non significative)			
Control vs all species	--	--	*	--

Organic C

Effects of intercropped species on soil organic C have not already been detected after 6 years of intercropping (Table 3). It has been sbown that total organic C is not affected as mucb as labile forms of C, by tillage systems, even on long term experiments (7).

Table 3. **Effects of time and intercropped forage species, on organic C, measured on the (0-15 cm) tilled layer.**

Time (years)	2	4	6
	Organic C (gravimetric percentage)		
Timothy	2.38	2.34	2.39
Bromegrass	2.37	2.29	2.21
Timothy-clover mix	3.32	3.17	2.50
Clover	2.37	2.37	2.19
Alfalfa	2.56	2.59	2.40
Control	2.45	2.71	2.64

Porosity and permeability

Six years of intercropping forage species with corn bad no effects on air-filled and total porosities (Table 4), and on permeability (table 5). The same parameters measured after two and four years were not affected either by any treatments, and they were of the same magnitude (data not shown). The higher soil organic C in the timothy-clover mix plots at the beginning of the trial is consistently reflecting on porosity. The consistently high level of air-filled porosity and permeability for the six treatments over the years does not show any sign of limitation to soil productivity yet, probably because they are measured on large cores. However there is visual evidence of soil crusting in the control plots that already affects infiltration and aeration during corn growing season. Spring plowing may be partly responsible for the good porosity and permeability measured in the tilled layer year after year.

Table 4. Effects of 6 years of intercropped forage species, on porosity.

Porosity	5 kPa		10 kPa		total	
Depth (cm)	0-7	8-15	0-7	8-15	0-7	8-15
	------------------------Porosity (%)------------------------					
Timothy	17	17	19	19	54	54
Bromegrass	16	13	19	15	55	54
Timothy-clover mix	20	19	22	22	60	58
Clover	14	14	16	16	52	53
Alfalfa	18	16	20	18	55	54
Control	20	17	22	18	56	54

Table 5. Effects of time and intercropped forage species, on permeability (K sat.).

Depth (cm)	0-7	8-15	0-7	8-15	0-7	8-15
	--------------------K sat (mm sec^{-1})--------------------					
Timothy	.02	.02	.02	.03	.04	.08
Bromegrass	.02	.01	.02	.005	.08	.05
Timothy-clover mix	.03	.006	.07	.03	.08	.06
Clover	.02	.03	.04	.04	.10	.08
Alfalfa	.03	.03	.01	.04	.07	.07
Control	.04	.03	.05	.03	.10	.30

CONCLUSION

Among the soil parameters used to quantify soil quality, the MWD of the water-stable aggregates was the most sensitive to intercropped species. The fact that legumes species are faster acting on structure than grass species is seen as an advantage since legume species also reduce nitrogen fertilizer requirements. The beneficial effects of both the intercropped species and the short rotation, on soil structure should make this cropping system even more attractive to farmers having soils with a weak structure, and with a sensitivity to erosion and runoff.

Future research on this cropping system will be oriented to erosion and runoff measurements as well as to the more labile forms of organic C.

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RESTORATION OF SOIL PRODUCTIVITY ON A DEGRADED CHERNOZEM USING ORGANIC AND INORGANIC AMENDMENTS

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ABSTRACT

Many agricultural fields on the semi-arid Canadian prairie exhibit areas of inherently low productivity associated with loss of soil quality due to past erosion. This study compared the efficacy of various amendments in restoring productivity to an artificially degraded Chernozem in southern Alberta. In spring 1992, the Ap horizon (about 15 cm depth) was mechanically removed to simulate erosion. The fourteen amendment treatments included various livestock manures, crop residues, combinations of straw and chemical fertilizer and fertilizer alone. The manures and crop materials were incorporated into the degraded surface on an equivalent dry weight basis. The plots were seeded to spring wheat in 1992 and 1993. In 1992, biomass yields varied from 4 t ha^{-1} on a hog manure treatment to 0.7 t ha^{-1} on a barley straw + 200 kg ha^{-1} N treatment. In both years, yields from desurfaced plots amended with hog, poultry or old cattle manure were not significantly different from plots with no topsoil removal. There was a positive relationship between biomass yields and extractable P concentration. Plots amended with crop residues had higher amounts of water-aggregates than those amended with livestock manures or chemical fertilizers.

INTRODUCTION

Wind and water erosion are major soil degradation processes affecting sustainable land management on the Canadian prairies. Many fields throughout the region have localized areas of soils with low nutrient-supplying ability due to past erosion. While much attention has been focused on the prevention of further erosion through conservation tillage and residue management, little has been directed towards the restoration of previously eroded areas. Farmers have several options for correcting or compensating for soil erosion and restoring productivity to these soils. The commonest approach is to apply additional chemical fertilizer to eroded areas (e.g. knolls) to improve crop growth and reduce the potential of further erosion. Application of livestock manure is another option (1, 3) but only where manure is available on-farm or within a short distance. However, the value of manure as an amendment for restoring the productivity of slightly eroded land is sufficient to allow manure to be hauled further than would be the case on non-eroded land (2).

For farmers that do not have access to a manure supply, a possible restorative strategy may involve transporting crop residues (straw, hay) from productive areas to eroded areas of the farm. These residues could then be shredded and incorporated into the eroded surfaces, either alone, or in combination with chemical fertilizer to approximate a manure. However, the efficacy of such procedures in the restoration of soil productivity have not been field tested. Recently, there has been much interest in composting manures to reduce environmental problems such as odour and leaching of nitrates into groundwater (4). The restorative properties of composted manure compared to fresher materials applied to eroded soils has not been determined.

The objective of this study was to compare the relative effectiveness of various livestock manures, composted manure, crop residues and organic fertilizers in restoring productivity to an artificially eroded surface.

MATERIALS AND METHODS

The study was carried out at Lethbridge, Alberta on a sandy clay loam (52% sand, 20% silt and 28% clay) Dark Brown Chernozemic soil. In May 1992, the Ap horizon ($\approx$ 15 cm depth) was mechanically removed with an excavator to simulate erosion. The plot layout was a randomized complete block design with four replications of fourteen amendments. The plots were 10 x 6 m. The amendments included six animal manures: fresh, old, and composted cattle manure, cattle manure + wood shavings, hog manure, poultry manure; four crop residues: alfalfa (*Medicago sativa* L.) hay, pea (*Pisum sativum* L.) hay, barley (*Hordeum vulgare* L.) straw + 200 kg ha^{-1} of N, barley straw + 200 kg ha^{-1} of P_2O_5; two phosphate fertilizer rates: 200 and 400 kg ha^{-1} of P_2O_5; and two checks: eroded check (topsoil removed, no amendment), and topsoil check (no topsoil removed, no amendment).

The fresh cattle manure was about 6 months old and contained a large amount of wheat straw. The old cattle manure was from the same source but had been stockpiled for 2-3 yr. The composted manure came from a different source, and had been composted for 1 yr in large windrows which were regularly aerated. The poultry manure was from a broiler operation where wheat straw was used as litter. The solid hog manure was from a farrowing unit and contained wheat straw. The alfalfa hay, pea hay and barley straw had been harvested and baled in summer 1991. All amendments were applied on a dry weight basis at a rate of 20 t ha^{-1}. Total C, total N and C/N ratios for the organic amendments were determined using finely ground material (< 150 μm) in an automated elemental analyzer (Table 1). The amendments were incorporated into the soil surface to 10 cm depth with a

Table 1. Total C concentrations, total N concentrations and C/N ratios for organic amendments.

Amendment	Total C, g kg^{-1}	Total N, g kg^{-1}	C/N ratio
Fresh cattle manure	296	18.8	15.7
Old cattle manure	129	14.3	9.1
Composted cattle manure	100	9.7	10.3
Cattle manure + wood shavings	330	8.3	39.6
Hog manure	358	23.9	15.8
Poultry manure	315	39.6	8.0
Alfalfa hay	413	26.5	15.9
Pea hay	397	26.0	15.4
Barley straw	414	4.3	99.1

rototiller. Spring wheat (*Triticum aestivum* L.) was direct seeded on June 3, 1992, but was destroyed by a severe hail storm on August 2, 1992. No further amendments were applied and the site was again cropped to spring wheat in 1993. Before seeding in 1993, surface soil samples were taken for extractable P concentration and aggregate stability (5).

RESULTS AND DISCUSSION

Since no grain was harvested in the first year, biomass yields from both years (taken when the crop was fully headed-out) are presented (Table 2).

Table 2. Effect of amendment on biomass yields, t ha^{-1}, 1992-93.

Amendment	1992	1993
Fresh cattle manure	2.53	6.04
Old cattle manure	3.08	6.10
Composted cattle manure	2.86	5.11
Cattle manure + wood shavings	1.58	5.28
Hog manure	4.03	6.74
Poultry manure	3.63	6.48
Alfalfa hay	3.32	5.74
Pea hay	2.56	5.10
Barley straw + 200 kg ha^{-1} N	0.72	4.32
Barley straw + 200 kg ha^{-1} P_2O_5	1.99	4.76
200 kg ha^{-1} P_2O_5	1.57	5.90
400 kg ha^{-1} P_2O_5	1.95	5.79
Eroded check	1.23	4.36
Topsoil check	3.72	7.31
LSD ($P \leq 0.05$)	1.27	1.23

The 1992 results showed that hog manure, poultry manure, alfalfa hay, old and composted cattle manure were capable of restoring productivity to the capacity of the topsoil check treatment. There was no significant yield difference between any of the livestock manures, except that the hog manure was significantly higher yielding than the fresh cattle manure. The alfalfa hay was just as efficient as the livestock manures. The pea hay was as good as all the livestock manures except hog manure. Barley straw + 200 kg ha^{-1} of P_2O_5 was as beneficial as the three types of cattle manure. Adding P_2O_5 to barley straw resulted in significantly higher yields than adding N.

In 1993, there was no significant yield difference between hog, poultry, old cattle, fresh cattle manure, 200 kg ha^{-1} P_2O_5, 400 kg ha^{-1} P_2O_5 or alfalfa hay. Composted cattle manure yielded significantly lower than poultry and hog manure. Compared with the 1992 results, the 200 and 400 kg ha^{-1} P_2O_5 treatments showed increased effectiveness in 1993 in reducing the impact of erosion (Fig. 1). The P_2O_5 may be more available in the second year as P-

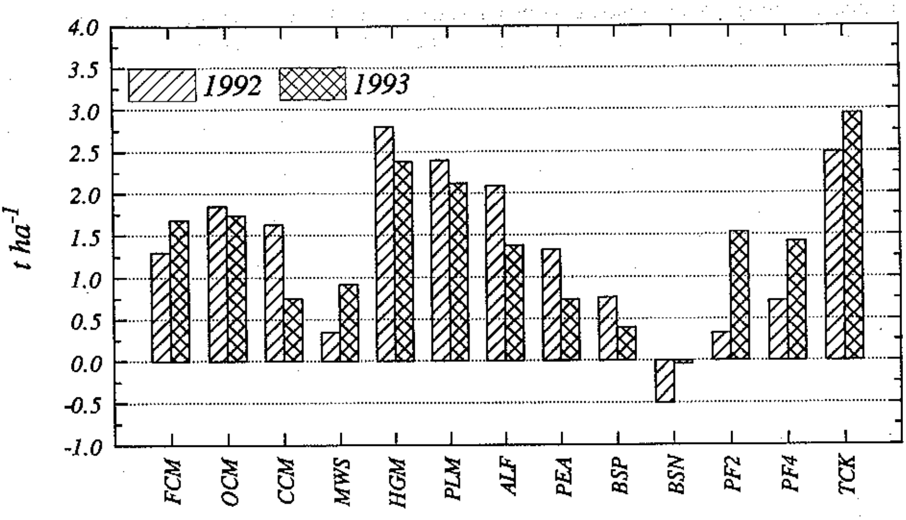

Fig. 1. Biomass yield differences between amended treatments and eroded check treatment, 1992-93. (FCM = Fresh cattle manure; OCM = Old cattle manure; CCM = Composted cattle manure; MWS = Cattle manure + wood shavings; HGM = Hog manure; PLM = Poultry manure; ALF = Alfalfa hay; PEA = Pea hay; BSP = Barley straw + 200 kg ha^{-1} P_2O_5; BSN = barley straw + 200 kg ha^{-1} N; PF2 = 200 kg ha^{-1} P_2O_5; PF4 = 400 kg ha^{-1} P_2O_5; TCK = Topsoil check).

binding carbonates are leached from the desurfaced plots. The composted cattle manure, alfalfa hay and pea hay and straw + 200 kg ha^{-1} P_2O_5 showed reduced effectiveness in the second year while poultry, hog, old cattle and fresh cattle manure showed similar effectiveness in both years (Fig. 1). There was little yield difference due to age of cattle manure. Averaging both years, the old cattle manure was slightly better at restoring productivity than fresh cattle manure or composted cattle manure (Fig. 1).

In both years, yields from desurfaced plots amended with hog, poultry or old cattle manure were not significantly different from plots with no topsoil removal, while yields from the cattle manure + wood shavings, and the barley straw + 200 kg ha^{-1} N treatments were not significantly different from the eroded check treatment.

The yield-restoring capability of the hog and poultry manure treatments may lie in their higher P-supplying power (Table 3). Seven of the treatments were able to supply P in excess of the non-eroded topsoil check treatment while six were not. There was a positive linear relationship between soil extractable P concentration and 1993 biomass yield (Fig. 2).

Percent water stable aggregates may be used as an index of susceptibility to water erosion: the lower the value then the higher the erosion risk. The crop residues were more effective in increasing aggregate stability then the animal manures (Table 3). Crop residues either alone (pea and alfalfa hay) or in combination with fertilizer (barley straw + N or P_2O_5) and resulted in higher stabilities than animal manures which were in turn higher than the fertilizer alone treatments (200 and 400 kg ha^{-1} P_2O_5). This is likely related to more readily available organic material in the crop residues compared with the livestock manures. Both check treatments (eroded and topsoil) resulted in the lowest aggregate stabilities.

Table 3. Effect of amendment on extractable P concentration, $\mu g\ g^{-1}$ 0-7.5 cm depth, and percent water stable aggregates, 0-2.5 cm depth, May 1993.

Amendment	Extractable P	Water Stable Aggregates
Fresh cattle manure	6.7	37.6
Old cattle manure	20.2	32.3
Composted cattle manure	15.3	36.6
Cattle manure + wood shavings	2.2	31.2
Hog manure	51.5	46.2
Poultry manure	31.4	39.5
Alfalfa hay	4.0	45.7
Pea hay	2.1	48.3
Barley straw + 200 kg ha^{-1} N	0.5	48.0
Barley straw + 200 kg ha^{-1} P_2O_5	14.8	45.4
200 kg ha^{-1} P_2O_5	14.2	29.9
400 kg ha^{-1} P_2O_5	27.5	28.6
Eroded check	0.9	28.5
Topsoil check	8.6	26.7
LSD ($P \leq 0.05$)	19.9	6.8

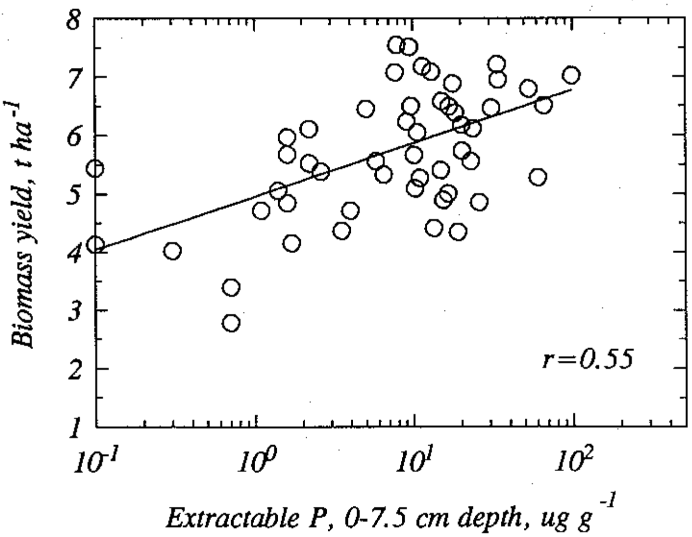

Fig. 2. Relationship between soil extractable P and biomass yield, 1993.

CONCLUSIONS

All amendments except the barley straw + 200 kg ha^{-1} of N were capable of increasing spring wheat yields above those of the erosion check treatment (15 cm topsoil removal, no amendment). Overall, the best amendment was hog manure, followed by poultry manure and old cattle manure. Alfalfa hay and pea hay were generally as good as the fresh, old or composted cattle manures. Cattle manure containing wood shavings was not as effective as the other types of cattle manure due to its lower N content and higher C/N ratio. The barley straw + fertilizer N and P did not prove to be an effective approximation of manure. This may be related to poor seeding conditions because of bulky straw residue which reduced emergence. High rates of P_2O_5, aimed at supplying P in excess of that which could be bound by carbonates were more effective in the second year. The effect of amendment on aggregate stability was of the order crop residues > livestock manures > fertilizer/check treatments.

ACKNOWLEDGMENTS

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LONG-TERM EFFECTS OF SUBSOIL COMPACTION ON NITROGEN YIELD OF ANNUAL CROPS

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ABSTRACT

The long-term effects of soil compaction by high axle load on crop growth were examined in field experiments on a heavy clay and an organic soil. The three treatments were: control without experimental traffic and one pass and four repeated passes with a tandem axle load of 16 Mg, with wheel tracks completely covering the plot area. The heavy traffic compacted both soils to a depth of 0.5 m. Mainly spring cereals - oats, wheat and barley - were grown in the nine following years. Nitrogen yields were determined each year. Although severe lodging of crops in the control treatment complicated the interpretation of results, soil compaction clearly decreased nitrogen yields of crops in many of the nine years. Decreases were especially notable, 8 - 19 kg ha^{-1}, for yields on the clay soil in the first three and the rainy sixth year. On both soils, relative nitrogen yield more sensitively measured the effect of soil compaction than did the relative seed yield. Taken as a mean of the first eight years, compaction of the clay soil in four passes reduced the nitrogen and seed yields by 9% and 4%, respectively. By comparison, the nitrogen yield as a mean of eight years, compaction of the organic soil in four passes decreased by 4% and seed yield by 1%. According to these results soil compaction due to high axle loads negatively influences nitrogen uptake and crop yield during many subsequent years.

INTRODUCTION

High axle load traffic can compact soil as deep down as the subsoil. This compaction has been reported to decrease grain yield for several years after the loading (1). Not only is the yield quantity affected but also the quality: for plough layer compaction has also been found to reduce the nitrogen content of grain (2) and grass silage (3). Soil compaction has not, however, always been observed to reduce the nitrogen content (4), and nitrogen content of oats has even been found higher on compacted plots (5). Despite the contradictory effects of soil compaction on nitrogen content, it usually reduces nitrogen yield (2,3,4,5) by lowering the efficiency of nitrogen uptake by a crop.

The long-term effects that soil compaction due to high axle load traffic has on yield quality and crop nutrient uptake have seldom been studied. To fill this gap, the effects of deep soil compaction on nitrogen and seed yields in nine subsequent years were studied in two field experiments at Jokioinen in South-Western Finland. The field experiments are part of an international study on the effects of heavy axle loads on soils (1).

MATERIALS AND METHODS

The field experiments were located on two soils: a clay soil (48% clay (< 0.002 mm) content in topsoil and 65% in subsoil) and an organic soil (to a depth of 0.4 m a mixture of well decomposed peat and clay, 19% organic carbon, underlying gyttja). The experiments were established in the autumn of 1981. The experimental traffic was applied with a tractor-trailer combination where the highest load on a tandem axle unit was 16 - 19 Mg. The treatments were: 0) control without experimental traffic, 1) one pass with the vehicle, wheel tracks completely covering the plot area and 4) four repeated passes as in 1). There were six replicates in the clay soil experiment and three in the organic soil experiment. Details of the experiments can be found in Ref. 6. In subsequent years no field traffic exceeded axle loads of 5 Mg.

On the clay soil, spring cereals of barley, wheat and oats were grown as a monoculture in eight subsequent years. There was also one crop rotation treatment in which spring oilseed rape (*Brassica rapa ssp. oleifera*), barley, grass (mixed timothy and red clover, 3 years), spring wheat, spring oilseed rape and barley were grown in succession. In the ninth year oats was grown on all plots. On the organic soil, in the first four years, barley was grown on half of the experimental area and spring oilseed rape on the other half. The two crops were alternated on the plots each year. After that barley was grown in two and oats in three subsequent years. Field operations for all compaction treatments were carried out on the same day, following common farming practice in Finland.

The crops were sown and fertilized with a combined drill which placed the NKP fertilizer between crop rows 2 - 3 cm deeper than seeds. Crop rows were 12.5 cm apart and fertilizer rows 25 cm. In the later years, nitrogen doses to the crops were reduced because of lodging (Table 1). For the grass, mixed timothy and clover, 10 kg N ha^{-1} a^{-1} was applied.

Table 1. Nitrogen fertilization (kg N ha^{-1}) during years 1 - 9.

Clay soil experiment		Organic soil experiment		
1-3	4-9	1	2-6	7-9
100	80-90	80	60	40

The total plot area was 90 m^2 and an area of 34 m^2 (annual crops) or 24 m^2 (grass) was harvested annually from the centre of the plot. The total nitrogen content of seed dry matter was measured by NIR (near infrared reflectance) technique (7), and the nitrogen yield harvested in the seed yield was calculated on the basis of the seed dry matter yield and nitrogen content.

RESULTS AND DISCUSSION

The high axle load traffic in 1981 compacted both soils to a depth of 0.5 m (6). Relative nitrogen and crop yields during nine subsequent years are shown in Figure 1 and Table 2. Especially on the organic soil, severe lodging of the crops in the control and in one pass compacted treatments complicated the interpretation of results for years 2 - 6. Moreover, crops failed on the organic soil in the sixth year and the results was not included in the mean yield results. Soil compaction decreased lodging of the crop thereby lessening the relative yield reduction caused by compaction. On both soils one pass with the high axle load influenced crop growing less than four passes did, in agreement with many earlier results (1).

Nitrogen and seed yield

The soil compaction decreased nitrogen and seed yields same years (Figure 1, Table 2). In both experiments, soil compaction decreased nitrogen yield relatively more than seed yield, for the reason that the compaction reduced both seed yield and nitrogen content of seeds. This is in agreement with the results of other groups (2,3). The nitrogen yield was thus the more sensitive measure of the influence of soil compaction. For instance, on the organic soil in years 2 - 5, relatively lower nitrogen yield than seed yield in the treatment with four passes indicates an effect of high axle load traffic. According to this result, only yield quantity does not always describe how harmful the effect of compaction on crops may be.

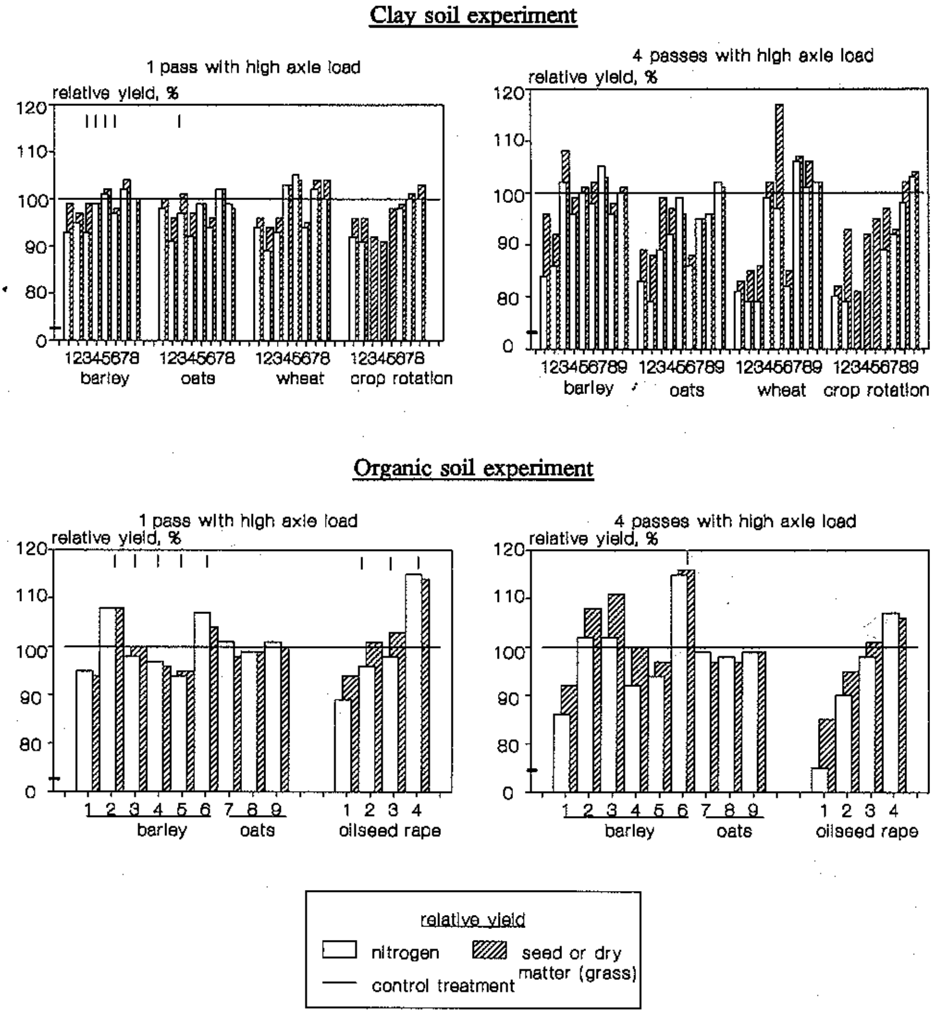

Figure 1. Relative crop and nitrogen yields during nine (1 - 9) successive years. I = crop lodged.

Both seed and nitrogen yields were significantly lower in the first three years on the plots compacted four times. Propably this was mainly due to plough layer compaction. After the first years the effect of compaction on yields diminished, partly for the reason that annual ploughing and freezing alleviated gradually plough layer compaction. However, although the soil froze to the depth of 0.5 - 1 m in six years, compaction in subsoil remained.

The effect of subsoil compaction on crop growth depended on the weather. When the precipitation at the beginning of the growing season was low, as years 5, 7, 8 and 9, subsoil compaction had little effect on nitrogen and seed yields. On the clay soil in fact, one of the control plots suffered from the drought exceptionally heavily, causing the lowest spring wheat yield in these years in the control treatment. Year 6, by contrast, was rainy and cool. For example, the precipitation in June was 39 mm higher and the mean temperature 1.7 °C lower than average. In that year, subsoil compaction reduced nitrogen and seed yields on the clay soil substantially. The reductions in yields were clearly due to the slow gas flux in the compacted subsoil, which stayed moist throughout the rainy summer.

Nitrogen uptake

The nitrogen yields shown in Figure 1 and Table 2 can be considered to represent the nitrogen uptake of the crops. In the first year of both experiments, nitrogen uptake of the crop in the control treatment was higher than nitrogen fertilization (see Table 1). This can be explained as a residual effect of fallowing of the experimental plots the previous year. In the organic soil, nitrogen mineralization was also high in later years.

Table 2. Mean seed (85% D.M.) and nitrogen (kg ha^{-1}) yields in control treatment (= 100 %) and yields, proportioned to the control, in compacted treatments during successive years. Lodging affected the results in the same years as in figure 1.

	Clay soil experiment						Organic soil experiment					
	Seed yield			Nitrogen yield			Seed yield			Nitrogen yield		
	Loading, passes			Loading, passes			Loading, passes			Loading, passes		
Subsequent	0	1	4	0	1	4	0	1	4	0	1	4
year	kg ha^{-1}	%	%	kg ha^{-1}	%	%	kg ha^{-1}	%	%	kg ha^{-1}	%	%
1	5040	98	88	106	88	82	4050	97	89	93	97	81
2	5280	96	90	83	90	81	3430	106	104	84	102	96
3	4110	99	98	73	98	89	1720	101	107	50	98	100
4	4240	100	98	74	98	95	2360	103	103	66	106	99
5	3410	102	105	69	105	99	4730	95	97	101	94	94
6	4240	97	93	69	93	88						
7	2200	103	100	50	100	99	4280	100	97	95	101	99
8	3550	101	101	77	101	98	6580	99	97	143	99	98
9	3300		102	78		102	7190	100	99	152	101	99
$x_{8yrs.}$	3880	99	96	75	97	91	4290	100	99	98	100	96

At maximum, soil compaction decreased nitrogen uptake of the crop by 20 kg ha^{-1}. Soil compaction can reduce nitrogen uptake in different ways. It can reduce plant nitrogen uptake or/and enhance denitrification. It can also reduce mineralization of soil organic nitrogen. For instance, in the first year compaction evidently reduced both nitrogen uptake of the crops and mineralization of N. In the rainy sixth year denitrification due to slow gas flux in the subsoil was probably the main reason for the losses.

An equal amount of fertilizer was applied in all treatments. Soil compaction reduced the efficiency of fertilization during several years by reducing nitrogen uptake of the crops. However, the results do not show, how much the compaction reduced the uptake of fertilizer nitrogen because of ^{15}N-technique was not used. Soil compaction can also enhance the the harmful impact of crop production on the environment, for instance, by increasing denitrification.

CONCLUSIONS

Soil compaction caused by high axle load traffic reduces crop value for several years after loading by reducing nitrogen uptake of crop, however, the negative effect of subsoil compaction depends on weather during growing season, being substantial only in rainy years.

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EGUSI-MELON (COLOCYNTHUS CITRULLUS L) RESPONSE TO COMPACTION DUE TO WHEEL TRAFFIC ON A SANDY LOAM ULTISOL

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ABSTRACT

A field experiment was conducted for four seasons to study the effects of tractor wheel traffic on soil physical properties and yield of egusi-melon on an Ultisol. The compaction was induced by 0, 1, 3, 5 and 10 passed (*wheel-to-wheel*) of a 58 KW tractor weighing 3150 kg.

Bulk density and penetration resistances increased with increase in tractor passes. The increases were 10. 9% and 466% for bulk density and penetration resistance respectively. Yield of egusi-melon generally decreased with increased tractor traffic intensity, yield reduction ranged from 8 to 40% when compared to the non trafficked treatment.

Relationships were developed between bulk density and penetration resistance and between them and crop yield.

INTRODUCTION.

In agricultural practice involving seedbed and rootbed preparation and other cultural operations using the tractor, compaction of the soil affects the soil physical environment for crop production. The intensive use of heavy tractors on agricultural soils have generated a lot of concern about the problems of excessive compaction. An important factor exerting a degrading influence on properties of all the soils is an intensive compaction with the wheels of machines and agricultural implements (Hakansson, et. al., 1988). Continuous passage of farm machines in agricultural fields can result in soil structure degradation which can be reflected in changes in soil physical properties such as bulk density, aeration, porosity, soil strength and hydraulic conductivity (Petelkau and Dannowski, 1990). Many scientists (Canarache, et. al., 1984; Domzal, et. al., 1991; Mckyes, et al., 1979; Negi, et. al., 1981; Ohu, et. al., 1991; Osuji, 1988; Raghavan, et., al., 1979; Taylor, et. al., 1981; Voorhees, 1978) have investigated the problems of traffic-induced soil compaction on different soils and their effect on different crop plants. They are unanimous in their verdict that the unfavourable changes in soil environment for plant growth and development due to compaction causes substantial decrease in yield. The degree of yield reduction differs from soil to soil, crop to crop and traffic intensity.

The work of many researchers on the above subject of compaction have not included egusi-melon which is of economic importance in many tropical countries. This paper reports the results of an experiment executed in four different seasons between 1989 and 1992 to ascertain the influence of different passes of tractor wheel on some soil properties and the yield of egusi-melon in the eastern part of Nigeria.

MATERIALS AND METHODS

The experiment was conducted at the Lake Nwaebere Campus (3 seasons) and at the permanent site (1 season) of the Federal University of Technology, Owerri. Both locations have well drained soil classified as Ultisol (Typic Tropodult) according to soil taxonomy (1975) with a sandy loam texture. New experimental areas were used for each season.

A completely randomized block design, consisting of four levels of compaction-tractor wheel passes of 1P, 3P, 5P and 10P with a no traffic (0P) control was laid out in the field. The compaction was applied by driving the tractor at a speed of 3.45km/hr through the assigned plots. The paths followed by the tractor wheels were carefully marked. The same trafficked portion was used for subsequent tractor passes as specified for each treatment. Each plot measured 6m x 25m with a headland of 5m between plots, The treatments were replicated three times. A 58 KW tractor weighing 3150 kg having rear tyre of size 16.9/14-30 and inflation pressure of 40 psi was used to induce compaction.

Ten core samples of 100 cm^3 were taken at random from each plot at depths of 0-5, 5-10, 10-15 and 15-20cm, for dry bulk density soil moisture, porosity and permeability measurements using conventional methods. Ten penetration resistance measurements per plot were done at same depths near the core sample points using a cone penetrometer of base 0.15m and core angle 30^0 operating at 1800mm/min. All soil mechanical and physical measurements were taken immediately after wheeling and seeding and at harvest to determine the effect of the tractor wheel intensity on the soil properties and yield of egusi-melon.

At harvest (which took place 75 - 80 days after seeding), fruits were manually gathered and processed for seed extraction,. Wet seeds were dried to 13% moisture content for storage. Number of fruits and fruit weight as well as dry seed weight were determined for each treatment on per hectare basis. Also the weight of 1,000 seeds from each treatment was also measured.

The average of all measured parameters for the four seasons were compared in terms of the traffic treatments while all data for the parameters were correlated with number of tractor wheel passes to establish some relationships between them.

RESULTS AND DISCUSSION

Soil Conditions:

Fig. 1 shows that while dry bulk density and penetration resistance increased with increase in number of passes of the tractor wheel (Domzal et al., 1991) porosity and permeability decreased. The increases were 10.9% and 466% for bulk density and penetration resistance respectively for the 10P treatment compared to the OP treatment. The bulk density relationship with number of passes was logarithmic and the others had linear relationships with the treatments. The parameters of their relationships are given in Table 1. The increase in number of passes of the tractor wheel reduced soil porosity and permeability by as much as 23.5% respectively at the 10P treatment.

Table 1: Regression equations between soil physical properties and number of tractor wheel passes.

Parameter	Relationship	A	B	r
Dry bulk density (Mg/m^3	Logarithmic[1]	0.253	0.041	0.996
Penetration resistance (MPa)	Linear	0.804	0.301	0.966
Porosity (% v/v)	Linear	54.740	-1.226	-0.981
Permeability (m/d)	Linear	19.552	-0.675	-0.972

[1]The equation is for (n+1) passes where n is the no. of tractor wheel passes.

The effect of wheel passes on soil properties varied with depth (Fig. 2). Wheel traffic increased dry bulk density appreciably in the 5 - 10 and 10 - 15cm depths (Fig. 2a) and penetration resistance in the same depth range (Fig. 2b). The 10P treatment had the highest bulk density (1.44 Mg/m^3) and highest penetration resistance (3.80 MPa) at the 10-15cm depth. Beyond this depth both parameters decreased for all the wheel passes including OP. It seems that wheel traffic forced soil moisture deep down the soil (Fig. 2c), since soil moisture content increased with depth for the 1P, 3P and 5P treatments. Beyond the 5-10cm depth there was no significant change in soil moisture content in the OP treatment. It was possible to establish positive linear relationships between dry bulk density and penetration resistance (Table 2) both of which increased with increase in number of tractor wheel passes (Fig. 2d).

Table 2: Linear regression equations between dry bulk density (Mg/m^3) and penetration resistance (MPa) for different numbers of tractor wheel passes.

Treatment	A	B	r
0P	-3.826	3.698	0.968
1P	-9.889	9.033	0.827
3P	-8.843	8.366	0.759
5P	-15.472	13.406	0.915
10P	-10.375	9.909	0.797

Crop Yield

Of all the yield parameters measured only the number of fruits decreased linearly with increase in the number of tractor wheel passes. The others decreased logarithmical with treatment (Fig. 3). The regression equations for the relationships are given in Table 3.

Table 3: Regression equations between egusi-melon yield parameters and number of tractor wheel passes.

Parameter	Relationship	A	B	r
Fruit wt (t/ha)	Logarithmic	3.426	-0.246	-0.945
Seed wt (Kg/ha)	"	6.457	-0.261	-0.964
Wt of 1000 seeds (g)	"	5.063	-0.089	-0.981
Number of fruits (/ha)	Linear "	5490.76	-423.89	-0.984

Increase in dry bulk density and penetration resistance due to tractor wheeling affected seed weight adversely. The relationships between egusi-melon seed weight and both parameters is given by:

$$SW = 3518.11 - 2243.63DD \ (r=0.979) \quad (1)$$

$$SW = 637.31 - 85.24\, PR \ (r= -0.872) \quad (2)$$

High soil strength is the greatest constraint for root growth and plant establishment. No wonder then the number of egusi-melon fruits decreased from 5.6×10^3/ha in the 0P to 1.5×10^3/ha in the 10P treatment - a decrease of about 73%, even though soil moisture was high below 10-15cm depth. Tractor wheel passes may have caused much compaction in the 0-10cm depth severely restricting root growth with subsequent less efficient utilization of subsoil nutrients and water. Also, since porosity and seed weight decreased with increase in number of tractor wheel passes, they were found to have a high positive correlation ($r = 0.836$).

$$SW = -548.4 + 20.4P_0 \quad (3)$$

Where SW = seed weight (kg/ha) and P_0 and P_0 = porosity (% v/v).DD = dry density (Mg/m^3) and PR = Penetration resistance (MPa)

These findings show that for egusi-melon production in a sandy-loam soil, tractor wheel pass of more than one reduces seed weight by over 32% and should therefore be avoided.

CONCLUSIONS

1. Increased tractor wheel passes increase soil density and penetration resistance to about 10.9% and 466% respectively.

2. Because of these and the reduction in porosity and permeability, all yield parameters measured decreased with increase in tractor wheel passes - 39.3% for fruit weight, 44% for seed weight.

3. Egusi-melon production in sandy loam soil may not require more than 1P of the tractor wheel for appreciable yield.

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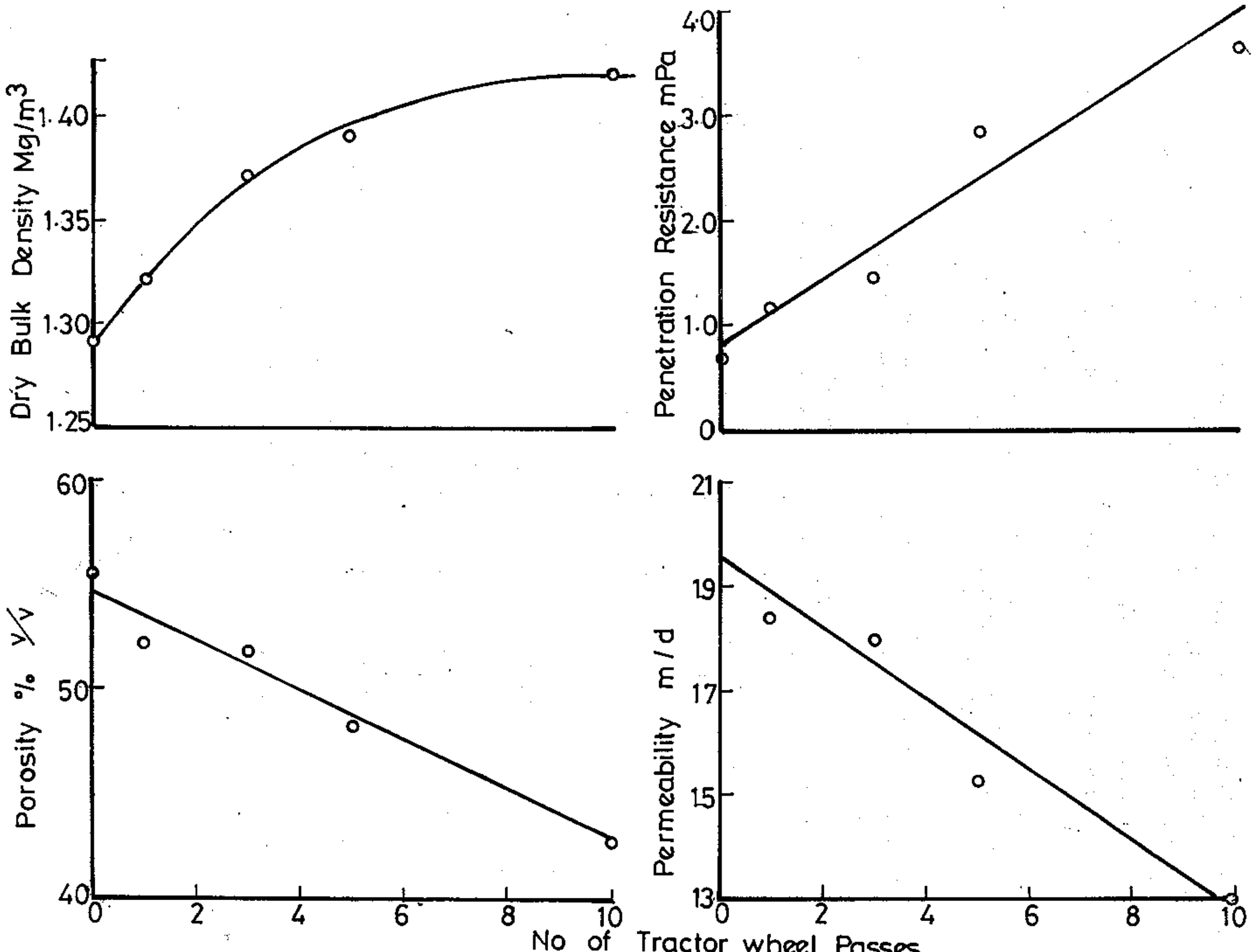

Fig.1: Effect of Tractor Wheel Passes on the Properties of a sandy loam ...

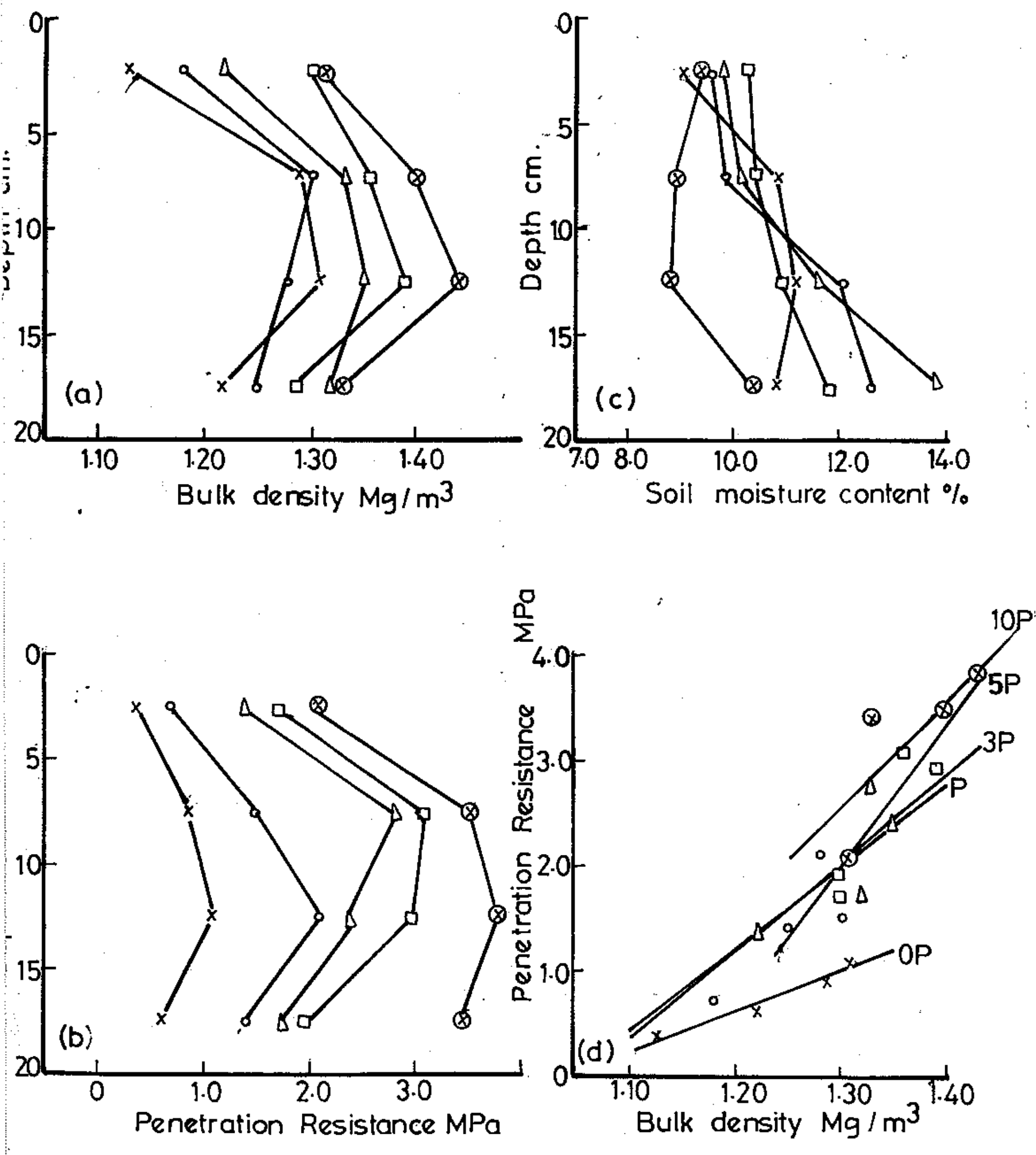

Fig.2: Effect of depth on bulk density (a) Penetration resistance (b) and Soil moisture (c) as well as relationships between Penetration resistance and Bulk density (d)

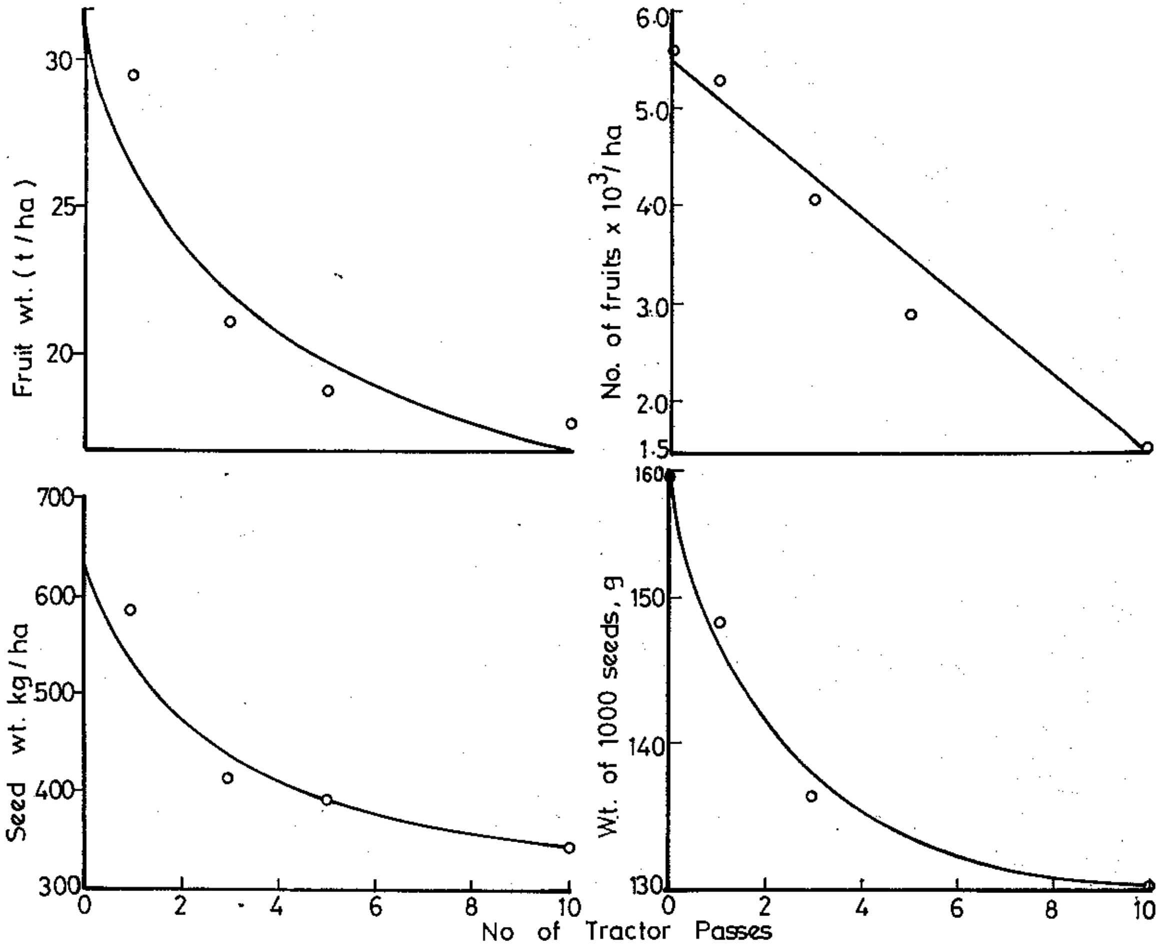

Fig.3: Effect of Tractor wheel Passes on the Yield of Egusi-melon grown on sandy loam ultisol

EFFECTS OF SOWING TECHNIQUES ON THE PHYSICAL CONDITION OF DIFFERENT SOIL TYPES

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ABSTRACT

An experiment was conducted over four years (1989 to 1992) in three soil types (chalky, loam and silt loam soils) to analyse the effects of sowing techniques on soil physical conditions during sugar beet establishment. Conventional sugar beet sowing (with mouldboard ploughing in winter and seed bed preparation in spring just before sugar beet sowing) and direct drilling of sugar beet into a catch crop (cereals or mustard) were compared for two sugar beet sowing dates. Soil structure (bulk density, aggregate size distribution, location of compacted areas), soil water content and soil temperature were recorded, sugar beet emergence dates were noted.

Soil compaction under the seed bed was less pronounced using direct drilling when the sugar beet was sown in early spring. With direct drilling, autumn soil tillage occurs in drier conditions than in spring for conventional sowing. The soil structure and soil water content in the topsoil layers before sugar beet sowing varied greatly according to the sowing techniques and soil types. The superficial tillage produced by the seed drill reduced these differences. Except in the silt soil that became strongly crusted during winter, seed bed physical conditions during sugar beet establishment were similar for all the sowing techniques.

INTRODUCTION

In the north of France, spring crops like sugar beet, are generally sown in seed beds prepared in spring just before sowing. For the past few years, a catch crop has sometimes been sown in autumn before spring crops in order to reduce nitrate leaching during winter. The catch crop can be either buried or chemically destroyed. If the catch crop is chemically destroyed, then sugar beet can be sown directly in the catch crop residues (figure 1). This technique requires no additional tillage after the catch crop sowing in autumn. Consequently, there is no soil tillage in spring because the seed bed was prepared in the autumn. There is thus less field work in spring, and sugar beet may be sown earlier, with a possible increase of sugar beet yield (1).

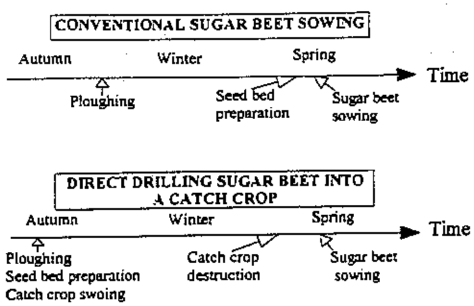

Figure 1 : Timing of tillage with conventional sowing and direct drilling

Direct drilling of sugar beet into a catch crop has two main differences from conventional sowing : the timing of tillage operations and the presence of a cover crop at the soil surface (2). As shown in figure 2, direct drilling of sugar beet into a catch crop may greatly alter the physical conditions in the soil, and this may affect seed drill function (3), seed placement and crop establishment. Contradictory effects are possible, and this makes it difficult to assess the overall effect of direct drilling sugar beet into a catch crop on sugar beet establishment and yield. These contradictory effects probably explain why the yield differences between direct drilling sugar beet into a catch crop and a conventional sowing of sugar beet vary greatly, depending on the soil and climatic conditions (4,5). The study reported here analyses and quantifies the effects of direct drilling on the main soil physical conditions : soil structure and soil water content. The experiments were conducted over several years in different soil types in order to reveal any possible interaction between the sowing technique and environmental conditions.

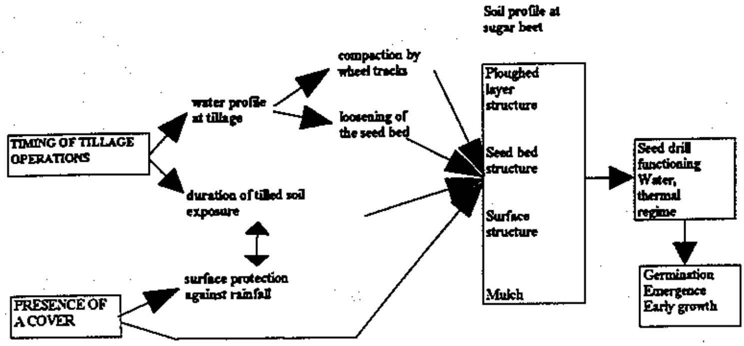

Figure 2 : Changes in soil structure and sugar beet establishment induced by direct drilling sugar beet into a catch crop

MATERIAL AND METHODS

Field experiments were conducted for four years in the north of France in three soil types : a chalky soil (with 75% $CaCO_3$) in 1989 and 1990, a loam soil with a high clay content (22% clay) in 1991 and a silt loam soil with a low clay content (14% clay) in 1992. Different sowing techniques were compared either for an early sugar beet sowing (beginning of March) or for a more usual sugar beet sowing date (beginning of April) :

- conventional sowing **(CS)** : mouldboard ploughing in winter, and seed bed preparation with a combined cultivator in spring, just before sugar beet sowing.
- direct drilling into rye **(DDR)** or mustard **(DDM)** : mouldboard ploughing, seed bed preparation and catch crop sowing in September. The catch crop was destroyed with glyphosate at the end of winter.
- direct drilling in a seed bed prepared in autumn **(DDA)**.

The structure of the arable layer was assessed by the method of Manichon (6), by mapping typical macroscopic structural features on the vertical face of a 6 m wide soil profile on one plot per treatment. The areas with a massive structure and no visible macropores were visually delimited on the soil profile and mapped. The location of wheel tracks on the plot was noted after each tillage operation. The soil profile was divided into three zones identified by the presence and origin of the fractor wheel tracks : zones with wheel tracks at sugar beet sowing (Z_1), zones with wheel tracks at seed bed preparation (Z_2), zones without any wheel tracks (Z_3). The proportion of the compacted areas with a massive structure and no visible macropores was assessed from the map of the soil profile in the three zones. Aggregate size distribution in the seed bed was assessed by dry sieving undisturbed soil samples taken from the sugar beet row (7 cm wide, 20 cm long), from the soil surface down the sowing depth. The soil water content in the ploughed layer was determined by the gravimetric method at each soil tillage operation and during sugar beet emergence. Soil temperature probes (thermistances) were placed 2 cm deep in sugar beet rows, with 3 replicates per plot. Soil temperature was recorded continuously with a time-step of 1 hour.

RESULTS AND DISCUSSION

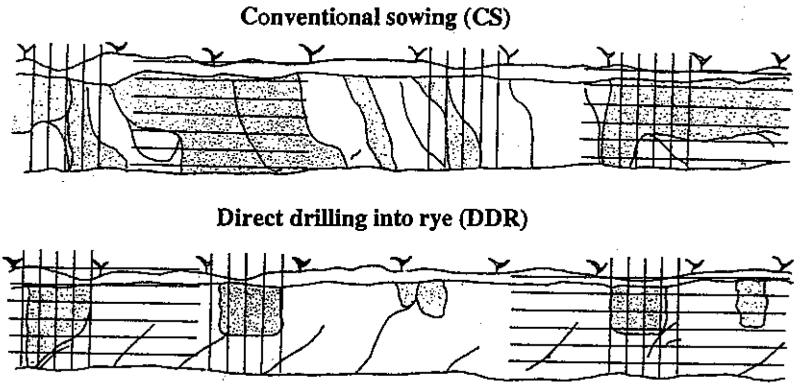

Figure 3 : Soil profiles observed after conventional sugar beet sowing and after direct drilling into a rye (experiment 1992, early sugar beet sowing)

:::: compacted areas with no macropores

|||| wheel tracks at sugar beet sowing

≡ wheel tracks at seed bed preparation (in autumn or spring)

Typical soil profiles are shown in figure 3 (experiment 1992). Compacted areas with a massive structure and without visible macropores accounted for 17% with direct drilling into rye and 40 % with conventional sowing in this experiment. The compacted areas correspond to the wheel tracks during sugar beet sowing for the direct drilling. For the conventional sowing, the compacted areas also correspond to the wheel tracks during seed bed preparation, which was done in early spring under much wetter conditions.

Table 1 :Fraction of areas with massive structure under the wheel tracks during seed bed preparation (which occured in autumn for direct drilling and in spring for conventional sowing)

	1989	**1990**	**1991**	**1992**
Direct drilling into a rye (DDR)	6	3	2	8
Direct drilling into a mustard (DDM)	*	6	8	8
Direct drilling into a seed bed prepared in autumn (DDA)	*	5	1	9
Conventional sowing 1(first sugar beet sowing) (CS)	46	22	16	61
Conventional sowing 2(second sugar beet sowing) (CS)	5	2	4	*

* : not done

Table 1 gives the proportion of compacted areas under wheel tracks at seed bed preparation for the 4 experiments. The most compacted treatment was conventional sowing at the first sugar beet sowing, early sowing at the beginning of March in wet conditions. Soil compaction was similar with direct drilling, whatever the catch crop, or with conventional sowing for a normal sowing date, in April, when soil had dried out. Direct early drilling sugar beet into a catch crop produced a less degraded soil structure, because most wheel tracks were made in dryer conditions. For a normal sugar beet sowing date, ploughed layer compaction with conventional sowing and direct drilling was the same. This result shows that soil compaction during seed bed preparation in spring only occurs if the water content of the ploughed layer is very high.

Figure 4 shows the aggregate size distribution in the seed beds for experiments 1991 in the loam soil and 1992 in the silt loam soil at three times :
- in autumn, immediately after catch crop sowing (time 1)
- in spring, immediately after seed bed preparation by conventional sowing (time 2)
- in spring, immediately after the first sugar beet sowing (time 3).

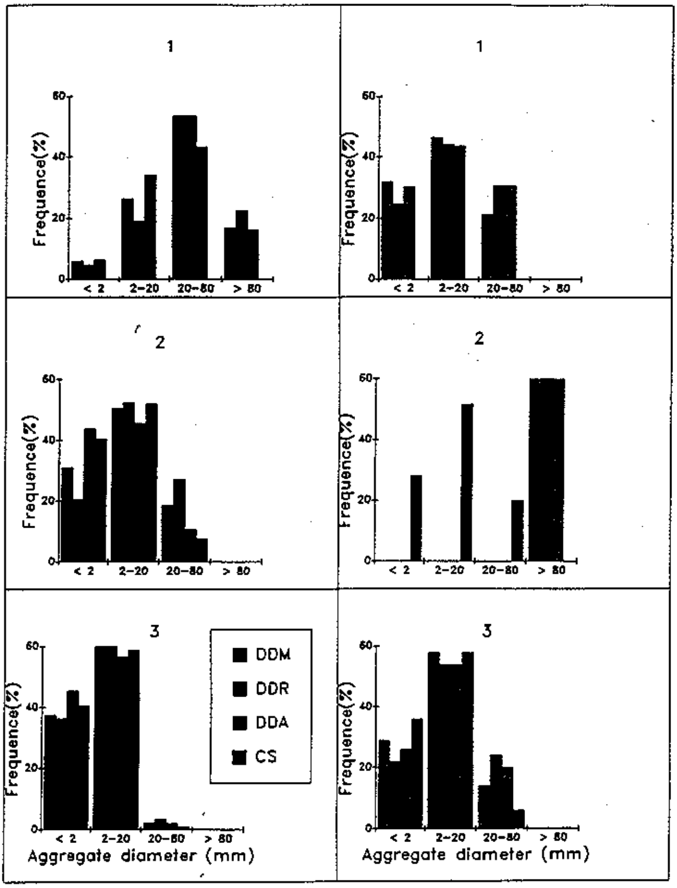

Figure 4 : Aggregate size distribution in the seed bed at 3 dates in autumn and spring

The aggregate size distribution changed in a very different way according to the experiment, *i.e.* the year and the soil texture. The seed bed was very coarse in autumn at catch crop sowing in the loam soil, while it was fine in the silt loam soil because of the high cohesion of the loam soil tilled in dry conditions. This initial relationship was completely reversed during winter :

- frost and wetting-drying cycles induced a sharp decrease in the mean aggregate size on the loam soil. The decrease was less pronounced under the rye crop.
- rainfall induced the formation of a thick dense crust on the silt loam soil, leaving no aggregate in spring, whatever the catch crop.

Seed bed structure obtained with conventional sowing was fine. The contrast between the seed bed structures obtained with the conventional sowing technique just after spring seed bed preparation and with the direct drilling under a catch crop was very pronounced, except in 1991 for a direct drilling without a catch crop. But there was less difference in the aggregate size distribution after the seed drill action. In 1991, seed bed structure after sugar beet sowing was very similar whatever the sowing technique. In 1992, the seed bed structure was coarser with a direct drilling of sugar beet into a catch crop, because the thick crust, which remained wet in spring, could not be completely broken by the loosening effect of the seed drill. In 1989 and 1990 in the chalky soil : seed bed structure was fine at catch crop sowing and remained fine during the winter because of the high stability of this soil.

Figure 5 shows typical change with time of seed bed water content. At sugar beet sowing, soil was wetter with direct drilling sugar beet into a catch crop. This was due to the effect of the mulch formed by the catch crop residues and to the breakage of soil water conductivity induced by the spring soil tillage. The tilled soil layer dried out more quickly. The difference in seed bed water content between conventional sowing and direct drilling was pronounced during the first days after the sugar beet sowing, but disappeared when it rained. After sugar beet sowing; the soil surface of direct drilling and conventional sowing gradually became similar because the seed drill removed the catch crop residues from the sugar beet row. Consequently, the evaporation regimes were probably very similar. Water from rainfall tended to homogenise water content to field capacity in the seed bed and the similar water regimes equalised the seed bed water content in the conventional sowing plots and direct drilling plots. Similar results were obtained for seed bed temperature (2).

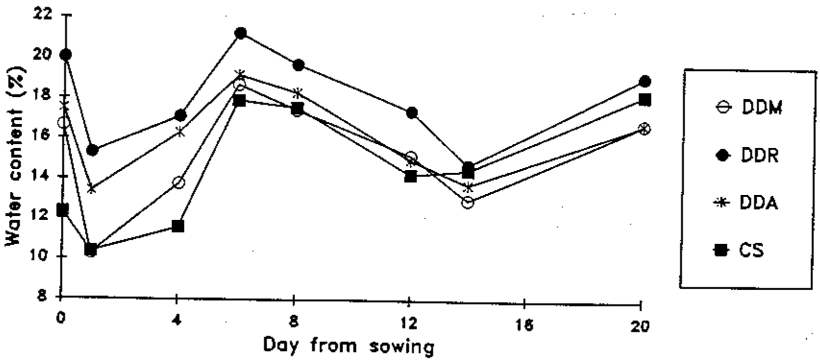

Figure 5 : Seed bed water content after sugar beet sowing (experiment 1992)

CONCLUSION

The main effect of direct drilling into a catch crop on soil physical conditionsis less compaction of the ploughed layer when sugar beet is sown early in spring. This effect is related to the time of seed bed preparation, and its subsequent effect on soil water content during soil tillage. The presence of a catch crop had no pronounced effect in our conditions, probably because catch crop aerial biomass was generally low (less than 1.5 t.ha-1) during its destruction . The specific loosening effect of the drill implements was very important for making the seed bed structure and seed bed water content after conventional sowing and direct drilling very similar. Drilling is clearly the most important tillage operations, and further studies examine the effect of soil structure and soil water content on seed drill function.

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EFFECT OF AXLE LOAD AND SUBSOILING ON MAIZE YIELDS ON THREE MIDWESTERN U.S. SOILS[1]

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Abstract:
A study was conducted at three sites in Iowa to determine the residual effects of large axle loads on maize yields. In addition, the experiment was designed to determine the effects of deep tillage (subsoiling) on crop yields when conducted prior to compaction, after compaction, both before and after compaction, and with no subsoiling. Main treatment effects were compaction loads, while subsoiling was the sub treatment effect in a split-plot design. Out of eleven site-years of data, only two site-years showed a significant yield reductions from one time axle load treatments. Subsoiling exhibited significant yield differences in only three of eight site years of experimentation. In two plot years, subsoiling resulted in yield reductions. Soils included in this experiment exhibited less detrimental effects from heavy axle loading than expected from previous research studies. Subsoiling after compaction did not produce consistent yield increases.

INTRODUCTION

The potential for soil compaction problems has increased in recent years due to larger, heavier field equipment with large axle loads. The potential for traffic on soils during vulnerable periods is also increased with larger field size. Earlier work has documented problems with heavy axle loads in many soils; Hakansson, et.al, 1987, Voorhees,et.al., 1988, Gameda, et.al, 1988, Lowery and Schuler, 1991.

In 1980, an International Working Group on Subsoil Compaction from High Axle Loads was formed to study the problem of long term subsoil compaction problems resulting from high axle loads. The objectives of the proposed research was to 1) determine the effect of high axle loads on the extent and persistence of subsoil compaction over a range of soil and climatic conditions, and 2) determine the effect of subsoil compaction on growth and yield of several crops (Anonymous, 1980). Studies have been conducted in many parts of Northern Europe and in the US.

STUDY OBJECTIVES

This study was established to follow the protocol of the International Working Group to determine the effects of subsoil compaction on maize (Zea mays L.) yields in three Iowa soils. A secondary objective was to determine the effects of deep tillage (subsoiling) on maize yields.

METHODS AND PROCEDURES

Three experimental sites in Central and Southeastern Iowa representing three different soil

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conditions were selected for this study. The three sites chosen were (1) an alluvial soil site on the Mississippi River bottom in SE Iowa (WEVER), (2) a site at the South East Iowa Research Farm (SERF), 40 KM south of Iowa City, and (3) a site on the Iowa State University Agricultural Engineering Research Center (AERC) near Ames. The soil at the Wever site is a Chequest silty clay loam. This soil is a fine, montmorillonitic, mesic, haplaquoll. The soil is a Kalona silty clay loam at the SE IA Research Farm. It is a fine, montmorillonitic, mesic typic hapaquoll. The soil is a Clarion-Nicollet complex at Ames. It is a fine-loamy, mixed, mesic, Hapludoll.

Past research results have indicated that soils with higher clay contents are more sensitive to compaction. Clay contents of the surface layer vary from approximately 27% at AERC to 37% at SERF.

The Working Group recommended that in the check treatment plot, axle loads in excess of 4.5 Mg should not be exceeded during the duration of the experiment. A 9 Mg axle load was recommended as the standard treatment. Additional treatments were a "9 Mg" track load and a 18 Mg axle load at two sites. The 18 Mg axle loading was included to represent axle loadings equivalent to large combines and grain wagons. The track treatment was included to compare the effect of a tracked vehicle with approximately the same total weight as a four wheel drive wheeled tractor with a 9 Mg axle load, hence the "9 Mg track" treatment. The tracked vehicle used had a gross weight of 15.1 Mg.

Plots were prepared and compacted in the fall of 1989. The plot area was tracked four times with wheelings from the appropriately loaded machine. Self loading, self propelled earth movers were used for the 9 Mg and 18 Mg loads at two sites. A 21 cubic meter single axle grain cart was used with appropriate grain loads to obtain the 9 Mg and 18 Mg axle loads at the Ames site. The 9 Mg tracked loading was accomplished with a rubber tracked tractor with a 15.1 Mg mass. Control plots received no tracking treatment. However, all subsequent operations will be done with equipment with less than 4.5 Mg axle loads.

SUBSOILING STUDIES

At two of the axle load experimental sites, Southeast Iowa Research Farm and the Agricultural Engineering Research Center near Ames, plots were established to allow the comparison of four different subsoiling tillage treatments; (1) no tillage, (2) pre-tillage before compaction of the plot, (3) post-tillage of the plot after compaction, and (4) both pre and post compaction tillage. Post tillage treatments were done in 1990 after harvest. Figure 1 illustrates the sub-plot arrangement. Since all the plots at the Wever Site had been previously deep tilled, only post tillage effects could be evaluated. Subsoiling was performed with a four shanked deep tiller, with 75 cm shank spacing, equipped with 10 cm wings, and operated at a depth of 45-50 cm (Model 1000, Yetter Manufacturing Company).[2]

Moisture Conditions

The purpose of the experiment was to investigate the long term effects on crop yield on a "one time" compaction event for relatively moist soils, near field capacity. The moisture level of the soils was slightly less than field capacity at each site when the compaction treatments were applied. Soil moisture was near field capacity in the upper 60 cm of soil, but the profiles were less than field capacity below 60 cm depth.

[2] Use of the product name implies no approval of the product to the exclusion of others that may be suitable.

WEVER

Figure 2 illustrates the annual yield response to a one time axle load placed in the fall of 1989 at the Wever site. Yields in 1990 were most affected by heavy axle load treatment at the Wever site. At the Wever site, the 9 Mg tracked loading had a significantly higher yields than yields from both the 9 and 18 Mg axle loadings in 1990. Yields were not significantly affected by compaction treatment in 1991 and 1992. All plot yield data was lost at the Wever site as a result of flooding in the area in 1993. Both 1990 and 1991 were dry years at the Wever site. Soil cracking was evident each year. The effects of soil cracking and crop growth may have been responsible for relieving adverse effects of the heavy axle loads.

SERF

Figure 3 illustrates the yield response to compaction treatments at the Southeast Research farm site. An 18 Mg axle load treatment was not applied at this site. No significant yield differences were experienced from axle loadings at this site from 1990-1992. After harvest in 1992, half of the plots were recompacted with two additional treatments, a 9 Mg load, and a 12.7 Mg load. These loads were place on the half of the plots where pre tillage had been administered in 1989. The 9 Mg load was placed on the original 9 Mg plots, while the 12.7 Mg load was place on the 9 Mg track plot. Statistically significant yield reductions were measured in 1993 from both loads. Excellent yields were obtained in 1990, but in 1991, yields were reduced as a result of dry weather. A mechanical problem at planting required that the plots be replanted in 1992. The late planting date affected average yields. The 9 Mg load treatment at this site was slightly lower than the control for both years, but not statistically significant at the 5% error level.

AERC

At AERC near Ames, the years 1990 through 1992 were relatively good crop years. In 1993, excessive precipitation during the growing season reduced yields. There was no statistically significant treatment effect at Ames for any of the years even though the trend was for both the 9 Mg axle and the 9 Mg track treatments to yield more than the control in all four years.

SUBSOILING

Plots were designed to evaluate the effect of deep tillage(subsoiling) on (a) the effect of deep tillage on maize yields after compaction treatments, and (b) the potential for recompaction after deep tillage for compaction treatments.

SERF

Subsoiling effects on maize yields are shown in figures 5,6, and 7. Figure 5 shows the effect of subsoiling on the Southeast Iowa Research Farm. Subsoiling effects were not statistically significant except for crop years 1991 and 1992 when subsoiling reduced yields.

AERC

Figure 6 illustrates the effect of subsoiling on the axle load treatments at the Agricultural Engineering Research Center near Ames. Subsoiling treatment effects were not significant except in 1993 when the presubsoiling and the pre and post subsoiling plot yields were significantly higher than the control.

WEVER

At Wever, plots were split into two sub treatments since the entire plot area had been deep tilled prior to compaction treatment loading. Subsoiling effects were not statistically significant at the 5 % level of significance, even though mean yields in subsoiled plots for both the 9 Mg and 18 Mg axle load plots were higher than those not subsoiled.

SUMMARY

1. Only one soil of three included in this study exhibited statistically significant yield loss from compaction loads, and then for only one year after the compaction treatment. Compaction effects may have been masked by other crop yield limiting factors such as moisture stress. Long term yield effects from heavy axle load treatments have not been experienced to date on the three soils studied in Iowa.

2. Subsoiling effects on yield of maize on the three soils studied were minimal. In two years at one site, subsoiling prior to compaction decreased yields, but the same treatment increased yields at one site for one year. Post treatment subsoiling did not statistically increase yields when averaged across all treatments.

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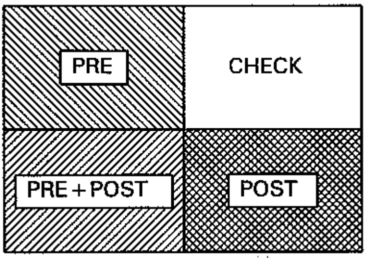

Figure 1. Layout of experimental unit.

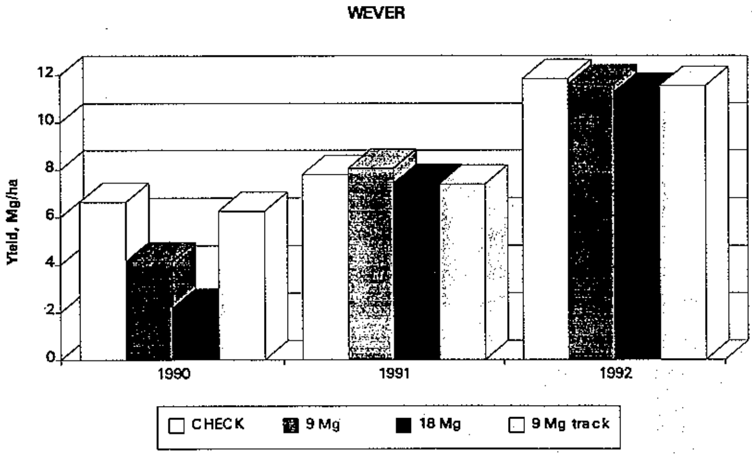

Figure 2. Yield vs main treatment at Wever

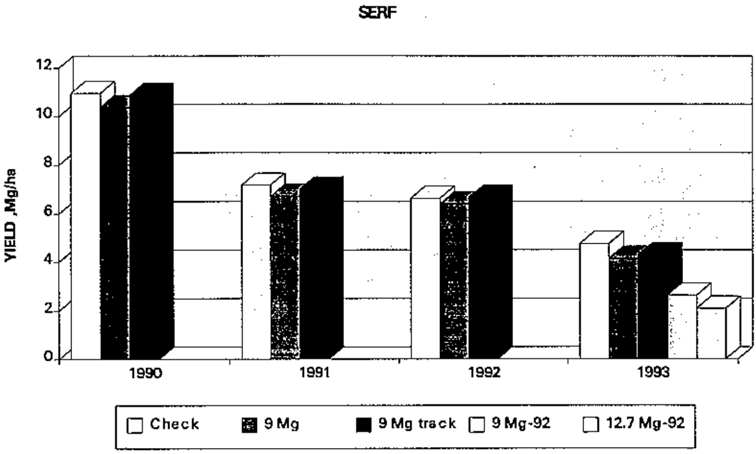

Figure 3. Yield vs treatment at SERF

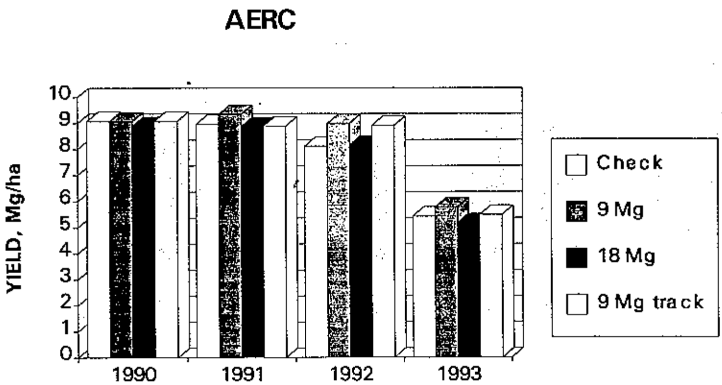

Figure 4. Yield vs treatment at AERC.

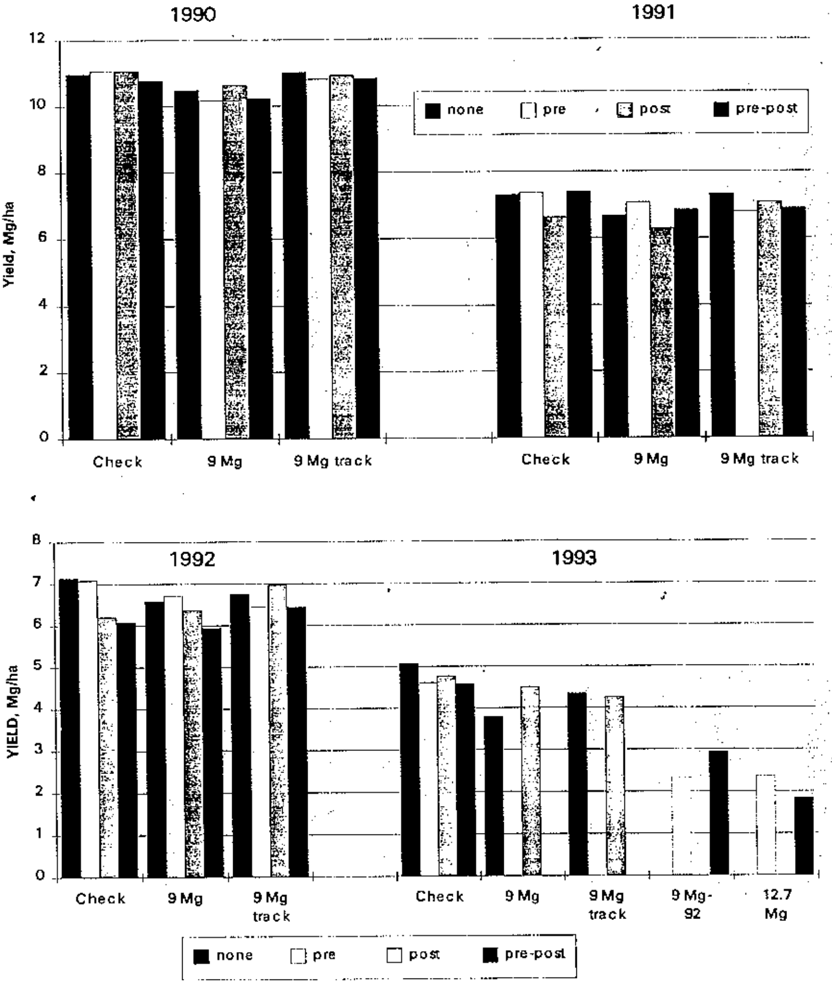

Figure 5. Yield vs subsoiling treatment SERF.

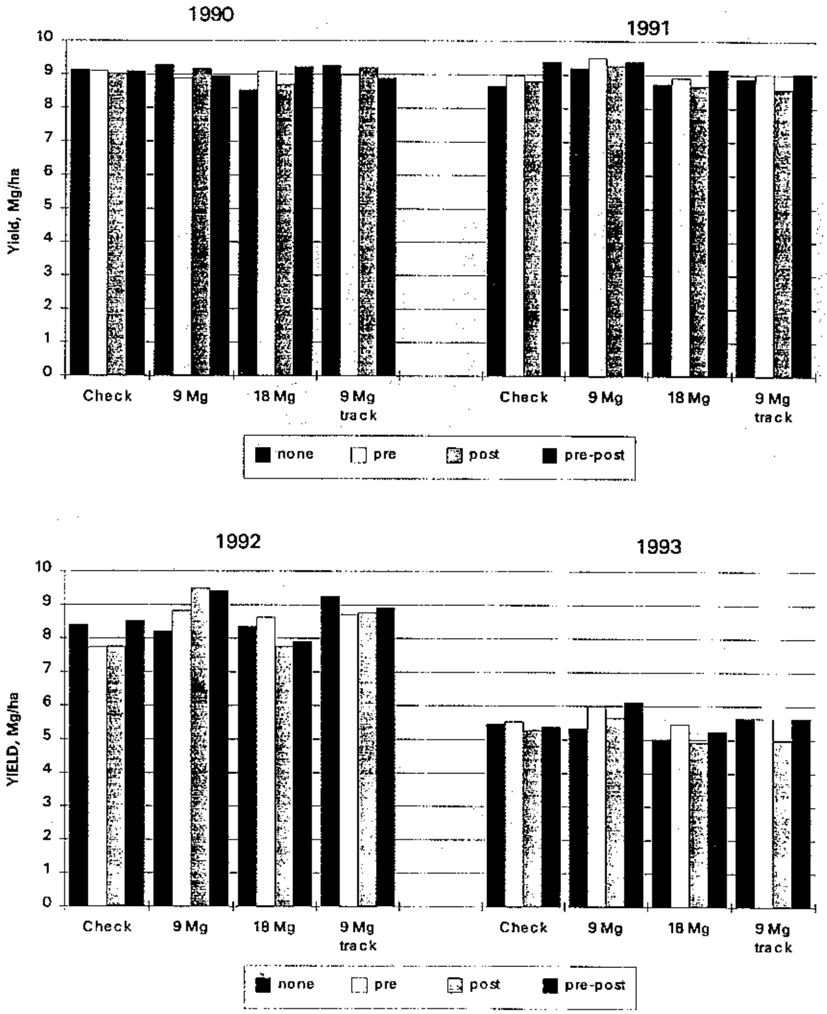

Figure 6. Yield vs subsoiling treatment AERC

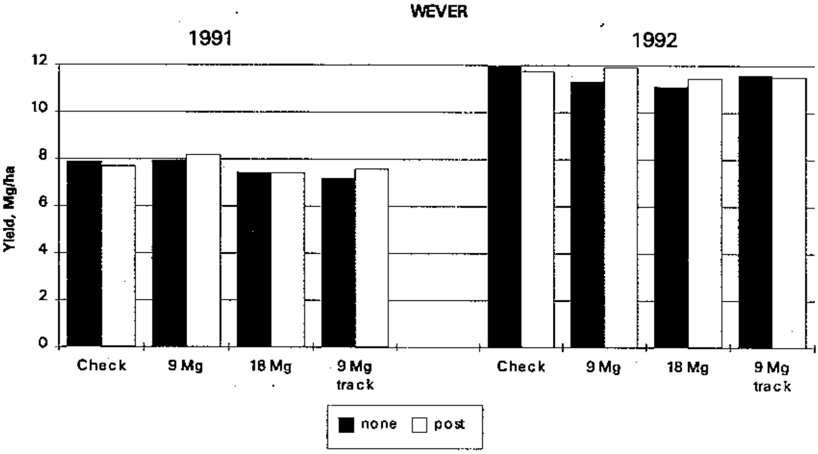

Figure 7. Yield vs subsoiling treatment, Wever.

THE INFLUENCE OF CULTIVATION SYSTEM AND STRAW DISPOSAL METHOD ON NITRATE LEACHING FROM A BROWN CAMBISOL IN SW ENGLAND

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ABSTRACT

Three experimental regimes were used to assess nitrate leaching under different cultivation systems to establish winter wheat sequentially. Results from a field study, the laboratory analysis of undisturbed cores and from a predictive model all identified reductions in leaching when using direct drilling systems. Lower mineralisation rates associated with the lack of soil disturbance in direct drilled systems resulted in losses that were 50% of those from ploughed soils, with maximum concentrations of leachate that were well below the E.C. guide limit. The incorporation of cereal straw residues in the ploughed soils reduced nitrate losses by up to 24%, although réductions with tining and direct drilling were not apparent and subsequent weed and pest problems mean that such systems are not advisable for the sequential production of winter wheat. Both the modelling and core experiments identified that an increase in temperature significantly increased leaching losses due to higher mineralisation rates.

INTRODUCTION

With a ban on the burning of cereal straw taking effect in the UK from 1 January 1993 a large proportion of straw disposal is likely to be achieved by incorporation methods. Problems associated with reduced tillage and no tillage systems in the presence of straw residues in terms of yield penalties due to toxin production (1) and the incidence of disease and pests (2, 3, 4) may mean that such systems are abandoned in favour of traditional ploughing.

It is well documented that the incorporation of straw residues with high C:N ratios is an effective management technique for reducing the amount of nitrate in the soil available for leaching due to the immobilisation that occurs as straw decays, at least in the short term (5). However, this reduction in leaching due to incorporation may be countered by an increase in mineralisation associated with cultivations. Previous studies (6, 7) have identified higher levels of nitrate leaching from ploughed soils than from either tined or direct drilled soils. Yet, few works have analyzed nitrate losses from different cultivation systems with straw incorporation as an additional treatment. Also no research has been conducted in South West England where rainfall of approximately 1000 mm yr^{-1} and relatively mild autumn and winter temperatures may produce different patterns of nitrate movement than those observed in the traditional cereal lands of central and eastern England.

A research project began in 1983 to examine the fate of nitrates under contrasting cultivation conditions with and without the incorporation of cereal straw residues. This paper describes three areas of research; a field study, the laboratory analysis of undisturbed cores and the use of computer modelling techniques. The results, when combined, provide a thorough understanding of how different cultivation systems influence levels of nitrate leaching from silty loam soils in SW England under continuous winter wheat production.

EXPERIMENTAL METHODS

The Field Study

The field study was conducted on a long-term cultivation trial site located near Newton Abbot, Devon, SW England. The site, 60 m a.s.l, has a uniform slope of between 1 and 2% to the south west. The silty clay loam soils (brown cambisols) are part of the Denbigh Association (8). The trial site includes well and imperfectly drained members. Weakly structured and with a high silt content they are unstable and prone to machinery damage. Depth to bedrock ranges from 450 - 650 mm over the plots.

The site was set up in 1983 using three cultivation techniques; ploughing, tining and direct drilling, to establish winter wheat sequentially. The three treatments were replicated randomly in three blocks, making nine plots in total. Each plot measured 50 x 5 m. Prior to 1991 all the straw residues were burnt. However, following the last three harvests the straw has been incorporated in half of each of the plots, so producing eighteen sub-plots and six treatments.

Following drilling in the autumn of 1992 detailed measurements were taken over a three month period to establish the levels of nitrate leaching from the plots. Mercury manometer tensiometers and time domain reflectometry probes were inserted in each sub-plot to depths of 100, 200, 300, and 400 mm to monitor soil water tension and soil water content. Ceramic suction cup samplers were inserted in each sub-plot to a depth of 400 mm and soil water was extracted at ten day intervals. Nitrate concentrations of the soil water were determined colorimetrically after reduction to nitrite (9).

With the assumption that once winter mean water capacity had been reached all water entering the soil profile from rainfall would drain vertically it is possible to estimate the nitrogen load leaching from each sub-plot. This can be achieved by applying the trapezoidal rule and calculating the area under the curve of the graph of nitrate concentrations plotted against cumulative rainfall.

The Analysis of Undisturbed Cores

In an attempt to gain a greater understanding of the leaching potential of individual storm events and also to further examine how different cultivations influence drainage patterns an experiment using undisturbed cores as mini-lysimeters was conducted. Four cores of each of the six treatments were removed from the trial site using lengths of heavy duty drainage piping and installed in the laboratory so that water draining through each core could be collected. Each core measured 200 mm in diameter with a depth of 400 mm and was sealed around the edges with grease to restrict preferential flow between the soil and the plastic piping. Over an eight week period a series of simulated storm events were applied to each core. The volume of leachate from each core and the nitrate concentration of that leachate was measured 24 hours after each event was applied.

The Use of Computer Modelling Techniques

The model LEACHN (10) was used to estimate leaching from the field site. As well as increasing the understanding of the processes involved in the removal of nitrates through leaching the model also enabled the investigation of other key systems in the nitrogen cycle not included in the field study such as denitrification. In addition the model allowed the estimation of nitrogen losses occurring during time periods beyond the scope of the field study. It was also possible to investigate a range of scenarios to determine the effects of extreme meteorological conditions on leaching losses. This idea was extended to examine the effects of varying the timing and depth of cultivation operations and of changing the type and volume of straw residues being incorporated. The ultimate aim of this final exercise being to formulate management strategies that could be adopted by farmers in the region to reduce nitrate leaching.

RESULTS AND DISCUSSION

From field measurements it was estimated that leaching from ploughed plots without straw between 21/10/92 and 24/12/92 was almost double that from direct drilled plots and 25% higher than from tined plots (Table 1). Analysis of concentrations recorded over the two month period identified a significant difference ($p < 0.01$) between ploughed and direct drilled treatments but not between tined and other treatments.

The greater leaching associated with ploughing is due to high rates of mineralisation that follow the disturbance of the soil at cultivation. The break up of soil aggregates exposes substrates to microbial activity and also encourages the organic matter breakdown with the increase of aeration in the soil. Similar results were reported (6) who observed nitrate leaching under ploughing to be 29% higher than that under direct drilling.

With the straw incorporation, leaching from ploughed plots was reduced by 24% to 7.93 kg N ha^{-1} and the maximum concentration observed was 5.4 mg NO_3-N l^{-1} as opposed to 7.8 mg NO_3-N l^{-1}. An analysis of variance of the nitrate concentrations recorded at each sampling date identified straw incorporation as being a significant treatment. (5) observed reductions in leaching of 22% with the incorporation of straw under ploughing. There was no significant reduction in leaching with straw incorporated into the tined and direct drilled treatments. This may be due to the lack of straw:soil mixing and consequently a reduction in its decomposition and subsequent immobilisation of nitrates.

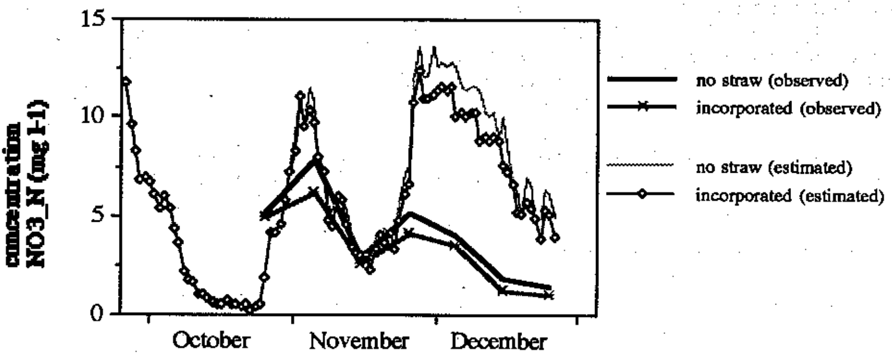
Following the first year of incorporation there were no significant yield penalties with any of the three cultivation treatments. However the establishment of a crop on the direct drilled plots where straw was left on the surface for the second year running was not successful and plant numbers were exceptionally low (< 20 plants m^{-2}). The role of direct drilling in conjunction with plant residues on a long-term basis must therefore be highly questionable.

Table 1 Observed and estimated leaching from the field between 21/10/92 and 24/12/92

	Total load (kg N ha^{-1})			Maximum concentration (mg NO_3-N l^{-1})	
Treatment	Observed	S.E.	Estimated	Observed	Estimated
direct drilled (no straw)	5.30	0.934	5.61	3.8	7.9
direct drilled (incorporated)	5.55	0.726	4.76	4.2	7.7
tined (no straw)	8.08	1.865	9.02	5.2	14.2
tined (incorporated)	8.33	1.456	8.21	5.2	12.2
ploughed (no straw)	10.43	1.139	9.95	7.9	14.2
ploughed (incorporated)	7.81	0.809	8.09	6.2	13.1

Although the predicted and observed values of total leaching are relatively similar the observed values for concentrations of nitrate-nitrogen are consistently lower than those predicted by modelling (Figure 1). This is due to the fact that suction samplers cannot effectively sample peak concentrations as the samples are only a mean of the water in the profile over the time period that the suction remains in place. Detailed field measurements began following drilling on the 21/10/92 whereas the model calculated leaching from the date of cultivation. Field measurements ceased in late December as concentrations of nitrates in the samples obtained from the suction samplers were very low and therefore giving only a minimal contribution to overall losses.

Figure 1 Observed and estimated concentrations of NO_3-N leaching from ploughed plots (date of drilling 21 October)



Losses of nitrate from the mini lysimeters were far greater than those observed in either the field or the modelling work (Table 2). These higher levels can be attributed to increased mineralisation rates caused by disturbance during the collection of the core and also higher temperatures in the laboratory than were experienced in the field (a mean of 12°C as opposed to 7.9°C). Also the fact that the cores are freely draining may result in greater losses. Far higher leaching losses from drained plots than from undrained plots have been observed by other workers (6). However although total losses observed in the field and core experiments are quite different the relationship between the treatments is very strong with a correlation coefficient of 0.96.

Table 2 Leaching from mini-lysimeters

Treatment	Total load (kg N ha^{-1})	S.E.
direct drilled (no straw)	9.4	0.62
direct drilled (incorporated)	7.9	1.64
tined (no straw)	17.7	1.41
tined (incorporated)	16.3	2.42
ploughed (no straw)	22.3	1.60
ploughed (incorporated)	13.3	2.09

Field measurenients did not reveal any significant differences in the soil water contents and soil water tensions of each of the six treatments.In addition there were no significant differences observed in the volume of water draining from the cores of each of the three cultivation treatments although the presence of macropores in some of the direct drilled cores did make the results highly variable. The similarity of soil water characteristics indicates that the differential leaching losses are a function of the concentration of the leachate and not a function of any drainage differences.

The modelling of different scenarios established that meteorological conditions can have a large effect on leaching losses (Table 3) with a rise of only 2°C increasing mineralisation rates and increasing losses by 14%. Although increasing rainfall tended to increase leaching levels the model predicted that during an extremely wet period with rainfall over 175% of the long term mean anaerobic conditions would develop and denitrification levels would rise and so in effect reduce leaching losses.

Effective management strategies to minimise losses when ploughing is adopted as a cultivation technique, include the incorporation of large volumes of cereal straw which reduces leaching by 26%. Obviously the practicalities of incorporating large amounts of straw successfully into the seed-bed and the consequences of this on seedling establishment may restrict the use of the practice as a management technique. The incorporation of residues with lower C:N ratios, such as rape stubble, result in an small increase in leaching rather than a reduction as the rapid breakdown of the nitrogen rich residues release nitrates rather than immobilising them. Care must therefore be taken not to incorporate such residues too early as an any delay in the establishment of a crop would allow nitrates to be removed from the system instead of being conserved by plant uptake.

Table 3 Predicted nitrogen losses from ploughed soils under a range of meteorological conditions and management strategies (kg N ha^{-1})

Treatment	Leaching losses	Denitrification losses
Control (straw removed and mean met. conditions)	9.15	2.22
rainfall 50% of LTM	5.67	0.94
rainfall 150% of LTM	11.24	3.13
rainfall 200% of LTM	8.61	5.16
mean temperatures - 2°C	7.96	2.60
mean temperatures + 2°C	10.48	1.85
+ wheat straw 5 t ha^{-1}	8.19	2.33
+ wheat straw 10 t ha^{-1}	7.24	2.74
+ OSR straw 4 t ha^{-1}	9.24	2.19
+ OSR straw 8 t ha^{-1}	9.34	2.19

CONCLUSIONS

The use of direct drilling techniques has been clearly identified as a method of reducing nitrate leaching, with recorded losses being as low as 50 % of those from conventional ploughing systems. Tined cultivation systems, which disturb the soil to a lesser extent than ploughing, result in leaching losses at an intermediate level between the two extremes. The incorporation of cereal straw has been successful in reducing nitrate losses by up to 24% with ploughing. However its failure to reduce leaching from tined and direct drilled plots, coupled with the inherent problems of weeds, pests and yield penalties associated with the presence of straw may mean that such treatments can only be used in rotation. No significant differences in the soil water contents, soil water potentials or drainage volumes of the treatment were identified, implying that differences in leaching losses are a function of concentration and not of drainage properties and that cultivations have a greater impact on the chemical processes occurring in the profile than on the soil water characteristics and drainage patterns of that profile.

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EFFECT OF SOIL TILLAGE AND RYEGRASS CATCH CROP ON NITRATE LEACHING FROM A COARSE SANDY SOIL AND A SANDY LOAM

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ABSTRACT

Two field experiments were conducted to evaluate the effects of tillage and growth of a catch crop on NO_3-N leaching.

On the sandy soil (1987-91) ploughing in autumn or in spring in combination with ryegrass as a catch crop was evaluated. Rotovating and direct drilling was also a part of the trial. The experiment was conducted in a 19 year old experiment with continuous production of barley.

On the sandy loam (1988-91) ploughing in autumn or in spring in combination with stubble cultivation and ryegrass as a catch crop in addition to minimum tillage was evaluated in a newly established experiment.

Porous ceramic cups were used to extract samples of soil water from a depth of 0.8 or 1.0 m. The content of water in the soil was measured by a neutron moisture meter.

On the sandy soil no significant effect of tillage was found. Leaching was significantly reduced by growth of a catch crop.

On the sandy loam a significant effect of tillage was found. Leaching from plots which were autumn ploughed without stubble cultivation was significantly higher than leaching from the corresponding spring ploughed plots. Plots which were stubble cultivated before ploughing showed no significant difference regarding ploughing time. Leaching was significantly reduced by the growth of a catch crop which was ploughed under in spring.

It should be mentioned that the experiment was conducted in relatively mild winters.

INTRODUCTION

Since the 1970's there has been growing public and political concern for the quality of surface and groundwater in Denmark. Leaching of nitrate from the root zone is of special concern.

Growing a catch crop is a method to decrease the nitrate content in the soil, thereby decreasing the risk of nitrate leaching (e.g. 1). Soil tillage has in some cases enhanced leaching (2,3) and in some cases reduced leaching (4). In other cases no significant differences were found regarding tillage (5).

The main purpose of the two experiments reported in the present paper was to evaluate the effects of tillage methods and growth of a catch crop on nitrate leaching from the rootzone of two soil types in Denmark.

MATERIALS AND METHOD

Two tillage experiments were established: 1) a four-year study (1987-1991) conducted in a 19 year old experiment with continuous production of barley (Hordeum vulgare L.) on a coarse sandy soil at Jyndevad Research Station, and 2) a three-year study (1980-1991) conducted in a newly-established experiment with continuous production of barley at Ødum Research Station. Both research stations are situated in Jutland, Denmark. The clay (< 2 μm), silt (2-20 μm), fine sand (20-200 μm) and the coarse sand (200-2000 μm) content for the coarse sandy soil is 4, 4, 12 and 77% (w/w), respectively and for the sandy loam 11, 17, 51 and 19% (w/w), respectively. At both sites the catch crop was undersown with perennial ryegrass (Lolium perenne L.).

Treatments and designs

Treatments on the coarse sandy soil (Jyndevad) were as follows:

A: Ploughing autumn.
B: Ploughing autumn, catch crop.
C: Ploughing spring, catch crop.
D: Ploughing spring.
E: Rotovating spring, catch crop.
F: Direct drilling.

N-levels:
X: 60 kg N/ha (treatment A - D)
Z: 120 kg N/ha (treatment A - F)

Treatments on the sandy loam soil (Ødum) were:

A: Stubble cultivating, ploughing autumn.
B: Stubble cultivating, ploughing spring.
C: Stubble cultivating, seed bed harrowing.
D: Ploughing autumn.
E: Ploughing autumn, catch crop.
F: Ploughing spring.
G: Ploughing spring, catch crop.

At both sites straw was removed from the plots after harvest. At Jyndevad plots that were not covered with catch crop were sprayed (glyposat) in autumn to destroy volunteers and weeds. Likewise, plots that were not stubble cultivated at Ødum were sprayed. The field at Jyndevad was irrigated.

At Jyndevad the experiment was arranged in an unrandomized strip plot design with four replications. At Ødum the experiment was arranged as a randomized complete block design with four replications.

Soil water sampling

Porous ceramic cup samplers with suction cups (type: 655x01-B1M1 from Soilmoisture Equioment Corp. in California) were installed at a depth of 0.8 m at Jyndevad and 1.0 m at Ødum to extract soil water. The cup samplers were constructed and installed as described by Djurhuus (1990) (6). Two samplers were installed in each plot. Samples were evacuated with intervals of 1-2 weeks in periods with expected percolation.

Each time sampling was carried out a suction of 0.8 bar was applied to each sampler. Three days later, the soil percolate was pumped to the surface and instantly frozen to prevent microbial activity. Immediately after thawing the samples were analyzed for NO3-N (7) after addition of tartrate.

Nitrate leaching was estimated by combining the calculated percolation with the corresponding values of nitrate concentration in soil water. The percolation was calculated by means of the model EVACROP (8).

RESULTS AND DISCUSSION

Jyndevad

Soil Tillage

From table 1 it appears that leaching from plots without a catch crop ploughed in spring (treatment D), autumn (treatment A) or directly drilled (treatment F) were not significantly different at any N-level. The trend was that leaching from plots directly drilled (treatment F) was less than leaching from ploughed plots (treatment A and D). A possible explanation for this trend could be that cultivating the soil gave rise to a slightly higher decomposition of organic matter in the soil than no-tillage did. Blevins et al. (1983) (9) found that no-tillage apparently was able to slow down the oxidation of organic matter originally present in the soil A reason why a significant effect of ploughing time was not found might be that ploughing in autumn was carried out rather late (November-December). Eventhough the experiment was conducted in four relatively mild winters the temperature at this time of the year might have been too low for mineralization to occur sufficiently to be significantly different from mineralization in unploughed plots. Another explanation for the results may be that the sandy soil was too coarse to give any significant protection of organic matter (discussed later).

Catch crop

At N-level 120 kg N/ha (table 1) leaching was significantly less in treatments including a catch crop (treatment B, C and E) compared to treatments without a catch crop (treatment A, D and F). At 60 kg N/ha the trend was the same even though the difference was not significant when ploughing was practiced in autumn.

The time of ploughing did not significantly affect nitrate leaching in plots including catch crops (treatment B and C), even though there was a trend showing that leaching was reduced the most by ploughing in spring. This lack of significance may be due to the fact that the C/N relationship of the underploughed ryegrass was in a range where no mineralization or immobilizsation was expected to take place immediately after incorporation (data not shown). In addition, as mentioned above, incorporation was carried out late in autumn where temperatures were low. Kyllingsbæk (1992) (10) found that incorporation of plant material in the middle of October caused a higher total leaching of nitrogen than incorporation in the middle of November.

Table 1 Leaching, kg NO_3-N per ha at Jyndevad and reduction (percentage) in leaching when growing a catch crop. Average of 4 years (1987-91). In bracket a value which is not significant.

N-level		60 kg N/ha	120 kg N/ha
Treatment			
A	ploughed autumn	44^{a}	62^{a}
B	ploughed autumn, catch crop	31^{ab}	42^{b}
C	ploughed spring, catch crop	20^{b}	31^{b}
D	ploughed spring	43^{a}	64^{a}
E	rotovated spring	-	32^{b}
F	directly drilled	-	55^{a}
LSD.95		16	12
reduction, ploughed autumn		(30%)	32%
reduction, ploughed spring		53%	52%

Ødum

Soil tillage

From table 2 it appears that tillage had a significant effect on NO_3-N leaching. Contrary to the results from the sandy soil there was an effect of ploughing time. Leaching from plots which were autumn ploughed without stubble cultivation (treatment D) were significantly higher than the corresponding spring ploughed plots (treatment F). When plots were stubble cultivated and additionally ploughed (treatments A and B) there was no significant effect of ploughing time though the trend was the same as mentioned above.

In spring ploughed plots (treatment B and F) leaching was significantly less if stubble cultivation in autumn was omitted (treatment F). In autumn ploughed plots (treatment A and D) the same trend was found but the effect was not significant.

One explanation for the difference in effect of cultivation between the two soil types of the experiment may be that soil organic matter was physically protected in the sandy loam. When cultivated, this protection may have been decreased. Adu and Oades (1976) (11) found that physical protection of organic matter was able to prevent decomposition. They also found that mechanical disturbance of aggregated soils caused a flush of microbial activity indicating that the accessibility of the organic matter was increased.

Catch crop

In spring-ploughed plots (table 2, treatment F and G) leaching was significantly reduced by growing a catch crop (treatment G). This was not the case in autumn ploughed plots (treatment D and E), where the catch crop only reduced leaching by 8 kg N/ha in an average of 3 years. This small reduction is probably due to the effect of ploughing in autumn. Ploughing in spring without a catch crop (treatment F) reduced leaching more, but not significantly more than underploughing the catch crop in autumn (treatment E).
effect of ploughing time though the trend was the same as mentioned above.

Table 2 Leaching, kg NO_3-N per ha at Ødum and reduction (percentage) in leaching when growing a catch crop. Average of 3 years (1988-91). Values followed by the same letter are not significantly different according to a Duncan-test. In bracket a value which is not significant.

Treatment		
A	stubble cultivation, ploughed autumn	76[a]
B	stubble cultivation, ploughed spring	63[ab]
C	stubble cultivation, seedbed harrowed	62[b]
D	ploughed autumn	65[ab]
E	ploughed autumn, ryegrass	57[bc]
F	ploughed spring	46[c]
G	ploughed spring, ryegrass	28[d]
reduction, ploughed autumn		(12%)
reduction, ploughed spring		39%

It should be mentioned that the experiment was conducted in relatively mild winters.

CONCLUSIONS

On the sandy soil no significant effect of tillage was found. The trend was that nitrate leaching from directly drilled plots, from an average of four years was less than leaching from ploughed plots.

Nitrate leaching was significantly reduced by growing catch crops. From an average of N-levels leaching was reduced by 31% when underploughing the catch crop in autumn and by 53% when underploughing it in spring.

On the sandy loam soil a significant effect of tillage was found. From an average of three years leaching from plots which were autumn ploughed without stubble cultivation were significantly higher than leaching from the corresponding spring ploughed plots.

Plots which were stubble cultivated before ploughing showed no significant difference according to ploughing time.

From spring ploughed plots leaching was significantly less if stubble cultivating in autumn was omitted compared to plots where stubble cultivating was practiced. In autumn ploughed plots the same trend was found, but the effect was not significant.

Growing catch crops reduced leaching by 39% when underploughing the catch crop in spring. Underploughing the catch crop in autumn did not significantly reduce leaching compared to autumn ploughing without a catch crop.

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EFFECT OF STRAW MANAGEMENT ON NITROGEN SOIL DYNAMICS AND NITRATE LEACHING.

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ABSTRACT

The aim of this work was to define strategies dedicated to reduce nitrate amounts in soil before the winter leaching period using straw incorporation. The influence of addition or not of wheat straw (8000 kg D.M. ha^{-1}) was investigated in bare soil in combination with 3 different soil tillage managements: no tillage, cover crop disk (10 cm depth) and rotavator (20 cm depth). Two experiments were carried out in different climatic conditions, but with the same soil. Water and mineral N content on a 150 cm profile and straw decomposition kinetics were measured during 12 months at 3 weeks intervals. A significant decrease of nitrate was observed in the horizon where straw was incorporated, due to nitrogen immobilisation by soil microflora during decomposition. The better the straw was incorporated (size of straw fragments and spatial distribution), the faster the decomposition occured and the stronger the immobilisation of nitrogen before winter has been. Straw addition to soil significantly decreased nitrate leaching during winter.

INTRODUCTION

The mineralisation of soil organic matter that occurs during autumn in Northern Europe in the intercropping period after cereals have been harvested leads to the accumulation of large amounts of nitrate in soil (1). This mineralisation alone seems to be sufficient to create nitrate pollution. Several ways of reducing nitrate leaching have been reviewed (2; 3). One of these is the incorporation of crop residues such as cereal straw, which has a high C-to-N ratio, into the soil. The added straw is designed to help heterotrophic microflora immobilise inorganic nitrogen during the decomposition of the C-substrates (4). Different strategies of straw management involving the physical properties and amounts of straw added, date and incorporation techniques, can considerably modify the kinetics of straw decomposition in soil and hence the soil N dynamics(5;6;7;8;9). The optimal strategy for reducing nitrate pollution would be to obtain maximal decomposition and nitrogen immobilisation before the beginning of water transfer to the deep layers of soil. But few studies have been published which had compare different methods of straw management in order to regulate nitrate dynamics during the autumn and winter (10). Present work was designed to compare different forms of contact between soil and straw, created by different soil tillage practices after harvest. The carbon decomposition and nitrogen dynamics (mineralisation and leaching) in soil were monitored in order to clarify the C and N relationships under field conditions.

MATERIALS AND METHODS

The investigation was carried out in Northern France in two experiments conducted after harvesting winter wheat crop during 12 months. The experiments were done on a loamy soil (18 % clay, 70 % loam; 8 % sand; 0.12% organic N; 1.2% organic C; pH 8). The effect of straw was investigated by comparing paired treatments with and without straw addition, receiving the same soil tillage. Straw (C-N ratio 120-130), ohtained from the 2 previous winter wheat crops, was spread uniformely over the soil surface by hand at a rate of 8000 kg D.M. ha^{-1}. The soil was then tilled. Three different soil tillage managements were compared, resulting in a total of 6 treatments:

- Mulch (MP) : ground straw (0-10 cm long) was left at the soil surface until the date of soil tillage in the spring. The control (M0P) consisted of no tillage until spring and no addition of straw.
- Rotavator (RP) : ground straw (0-10 cm long) was incorporated by rotavator into the top 0-20 cm of soil. The control (R0P) consisted of tbe same tillage without straw.
- Covercrop (CCP) : coarse straw (10-40 cm long) was incorporated into the top 0-10 cm by a cover crop disk. The control (CC0P) consisted of using the same soil tillage but with no residue.

The experiment began on 27/07/90 for the first experiment and 29/08/91 for the second experiment. Ploughing was done on the same dates for all 6 treatments : the 22/01/91 for the first year and the 3/03/92 for the second year.

Water and mineral N content were measured over 12 months at 3 weeks intervals on the 0-10 cm, 10-20 cm, 20-30 cm, 30-60 cm, 60-90 cm, 90-120 cm and 120-150 cm layers. The straw decomposition kinetics were assessed by measuring residual coarse straw in the top soil every 3 weeks.This fraction (size >1mm) was obtained by sieving the wet soil.

The effect of straw incorporation on the dynamics of nitrogen in soil was deduced by comparing the net accumulation of nitrogen in the soil profiles with and without straw for each type of tillage and by comparing the net mineralisation curves calculated for each pair of treatments (11). Potential nitráte losses below 90cm depth, were estimated from the N soil profiles measured at the beginning of drainage using a model of leaching derived from the equations of Burns' (12). This model takes into account the distribution of mineral N in the soil profile at the beginning of the drainage period and several rainfall patterns (varying amounts and time distributions).

RESULTS AND DISCUSSION

Straw decomposition

The changes in the straw coarse fraction (size > 1mm) for each treatment were significantly different. Decomposition was rapid during the autumn in the RP treatment soils in which the contact between soil and straw was the best: the mean rate of carbon disappearance was 0.4-0.5 tons C ha^{-1} $month^{-1}$. In contrast the change was very slow for the straw left as a mulch on the soil surface (MP), until it was incorporated by ploughing in the spring (0.05-0.1 tons C ha^{-1} $month^{-1}$). Decomposition was rapid after ploughing, so that one year later, the percentages of coarse straw remaining in the soil were essentially the same, at 10-15 % of the straw applied for all treatments and both years.

Dynamics of inorganic N in soil

The mineral N content of the soil increased rapidly due to the net mineralisation of soil organic matter after all treatments (figure 1). The average rate of mineralisation for the controls (R0P, CC0P and M0P) was about 0.5 kg N ha^{-1} day^{-1} during the autumn for both years. This lead to the net production of about 50 kg N ha^{-1} during this period. The net accumulation of nitrogen after 12 months was 140-160 kg N ha^{-1}. Soil tillage resulted in extra N mineralisation of about 10-15 kg N ha^{-1}.

Straw incorporation caused a significant decrease of the mineral N content of the soil, due to immobilisation of nitrogen by soil microflora, as shown for the year 1991-1992 in figure 1. The decrease in the mineral N content for CCP and RP was 20-30 kg N ha^{-1} from day 65 after incorporation to day 140. The difference then decreased a little, probably because of different rates of N leaching from the soils with and without straw. The difference between the treated straw plots and the controls again slowly increased after day 200 (18/03/92). For the plots in which straw had not been incorporate (MP and M0P), the straw on the soil surface had had very little or no effect on the N content of the soil before winter. The reduction in the soil nitrate content occured mainly after straw incorporation in the spring, and had a large, rapid effect at this time.

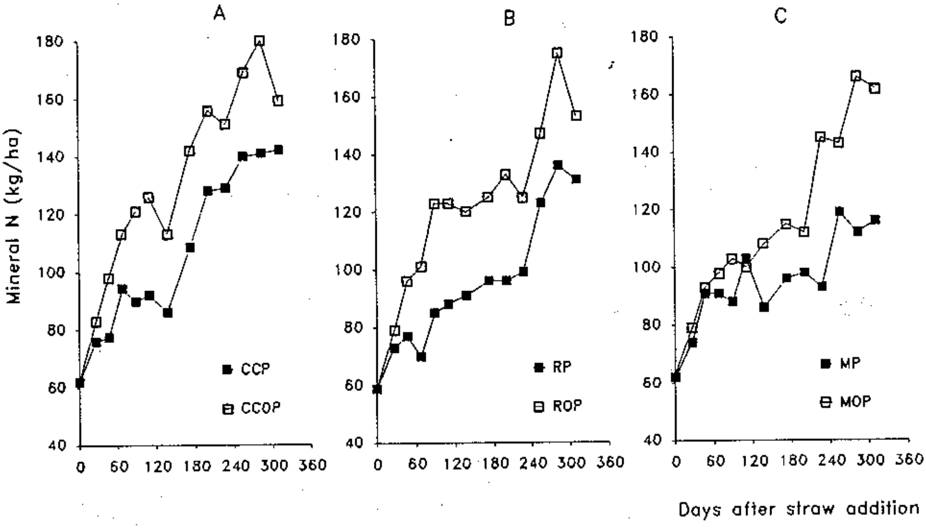

Figure 1 : Mineral nitrogen accumulation in a bare soil (0-150cm) during 12 months after wheat harvest. The soil received 3 different soil tillage managements: Cover crop disk (A), Rotavator (B) and no tillage (C). For each soil tillage management, plots with straw added at a rate of 8000 kg DM ha-1 (closed symbols) were compared with plots without straw addition (open symbols).
The day 0 is the date of addition of straw (29/08/1991). Values are the mean of 3 replicates.

Relationships between N and C dynamics

The estimation of net N immobilisation by comparing paired N soil profiles at each time was not very accurate because of the great variability of the mineral N measurements (11). However, there was a linear relationship between the amounts of nitrogen immobilised and the percent of C-straw decomposed for the 3 treatments and over the 2 years of observation (figure 2). The mean ratio between N immobilised and straw added was about 8 kg N ton^{-1} straw. It was much lower than the value of 15 kg N ton^{-1} straw found in other field and laboratory experiments (13;14). It is possible that the inorganic N, which was often depleted in the top layer where straw was incorporated, could have reduced the immobilisation ratio, as has been shown in laboratory conditions (14).

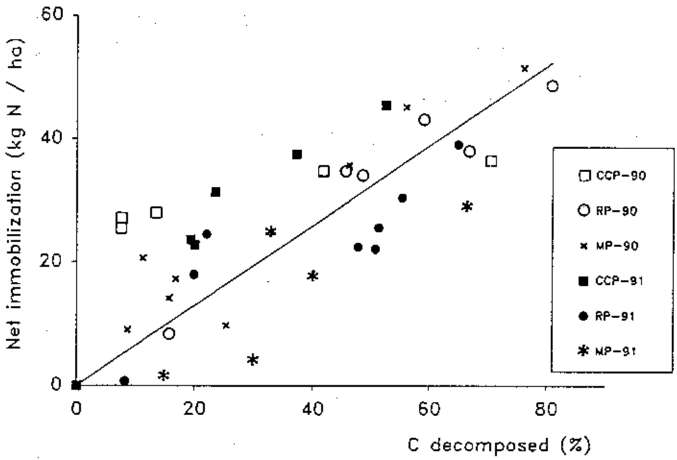

Figure 2 : Relationships between net N immobilisation and C decomposition (expressed as % C applied) for the 3 treatments (CCP, RP and MP) and the two years of experiment.

Nitrate leaching

The model for leaching derived from Burns was applied to the nitrate profiles in soils obtained by the 6 treatments, on 26/11/90 for the first experiment and on 13/11/91 for the second. The two winter periods were much drier than normal (<150 mm rain from 1/12 to 1/03), so that little leaching was calculated by the model (Table 1). This fact was confirmed by continuous water and nitrate measurements made in lysimeters on the same site (data not shown). Potential nitrate leaching was calculated using increasing amounts of rain. The amount of nitrate potentially leached below 90 cm depth was high even in plots to which straw had been added. Nitrate loss from the bare soil with no soil tillage (M0P) was a little lower than those calculated on CC0P and R0P treatments and this is due to the decrease in mineralisation. The incorporation of straw (CCP and RP) would have reduced nitrate leaching by 20-38 kg N ha^{-1} (winter 1990) or 8-28 kg N ha^{-1} (winter 1991) with 200-300 mm rain, which is common in this area during winter.. Straw left as a mulch on the soil surface (MP treatment) had little effect (1991) or a negative effect (1990) on nitrate loss. In fact, the mulch increased the water content of the soil top layer during the autumn 1990, and consequently the N mineralisation.

Table 1 : Simulation of nitrate loss below 90 cm soil depth using a model of leaching derived from Burns (1976). The simulation was done for the 1990-91 and 91-92 winter periods with different rainfall patterns (50 to 300 mm) using the nitrate profile obtained at the beginning of water transfer : (1) 26/11/1990 and (2) 13/11/1991 in plots without straw (CC0P, R0P and M0P) and with straw (CCP, RP and MP). The effect of straw on the reduction of nitrate leaching was calculated by comparing potential leaching for each pair of treatments.

Rain *(mm)*	**Potential N leaching** *(kg/ ha)*						**Reduction of leaching** *(kg/ ha)*		
	CCP	**CC0P**	**RP**	**R0P**	**MP**	**M0P**	**CCP -CC0P**	**RP -R0P**	**MP -M0P**
1990-91 N min 0-90(1)	39.4	78.8	36.3	78.8	72.9	70.9			
50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
100	1.7	2.3	1.1	2.2	8.3	2.0	-0.6	-1.1	6.3
150	9.4	16.7	7.8	15.8	24.9	14.6	-7.3	-8.0	10.3
200	21.5	40.8	18.9	39.0	44.4	36.0	-19.3	-20.1	8.4
250	31.2	60.5	28.0	58.9	59.3	53.9	-29.3	-30.9	5.4
300	36.4	71.6	33.0	70.8	67.5	64.2	-35.2	-37.8	3.3
1991-92 N min 0-90(2)	59.2	99.2	48.8	81.3	61.4	75.2			
50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
150	7.8	9.9	7.0	8.8	7.5	7.3	-2.1	-1.8	0.2
200	24.3	31.8	20.7	31.0	24.5	25.8	-7.5	-10.3	-1.3
250	41.3	55.7	34.3	54.8	42.1	47.2	-14.4	-20.5	-5.1
300	52.0	72.2	42.8	70.4	53.4	62.9	-20.2	-27.6	-9.5

CONCLUSION

The decomposition of wheat straw incorporated into the soil is strongly dependant on the degree of contact between soil and straw. Different types of management after wheat harvest can lead to very different kinetics of decomposition during the following year. Incorporation of the straw with a rotavator or by cover-crop provided better contact between the straw and the soil than did mulching. Decomposition after mulching was slower, resulting mainly from losses of solubles fractions. Immobilisation of nitrogen and decomposition occured in parallel. About 8 kg N were immobilised per 1000 kg of straw added. The smaller the particles of straw and the better they were incorporated into the soil, the more nitrate was depleted before winter. Soil tillage enhanced N mineralisation by about 10-15 kg N ha^{-1}, which was not sufficient to overcome the positive effect of straw incorporation. The decrease

in the mineral N content of the soil profile due to straw decomposition reduced the amount of nitrate available for leaching.
In conclusion, maximal immobilisation of nitrogen before the beginning of water transfer , requires cultural techniques that provide fast decomposition of straw after incorporation. The usual practices could be improved by obtaining more finely divided straw and spreading it more evenly throughout the tilled soil layer.

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NITRATE LEACHING IN RESPONSE TO TILLAGE AND COVER CROPPING PRACTICES

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ABSTRACT

Research to evaluate the effects of tillage [conventional (CT) vs. no-tillage (NT)] and winter cover cropping [rye (R) vs. fallow (F)] on NO_3-N leaching from cropland used for maize grain production was conducted. The study area consisted of twelve 10 by 100 m plots where maize is grown using a factorial combination of tillage and winter cover treatments. Tile drainage flow volumes and associated NO_3-N concentrations were measured from each plot. Thirty months of data have been collected. NT gave the largest flow volume. NO_3-N leaching interacted with tillage, rainfall and maize biomatter production. The winter fallow treatments, particularly the CT, gave the greatest NO_3-N leaching. Rye winter cover crops can be effectively used to reduce NO_3-N leaching.

INTRODUCTION

Concern about reductions in both water and atmospheric quality losses and the potentially harmful environmental damages associated with excessive agricultural nitrogen (N) is widely recognized and continues to increase (2,7,10 and 17). The NO_3-N content of drainage water may also be a predominating factor associated with the amount of bases in leachate (13). Heavy use of N resources in maize (*Zea mays* L.) production has been implicated as an extensive source of NO_3-N delivered to ground and surface waters in the eastern USA (6). Following the adoption of two new policies by the European Community, nitrate leaching has become the subject of widespread concern (10). Since NO_3-N leaching is strongly influenced by soil and crop management (18 and 14), there is great need to assess NO_3-N leaching losses in the new maize production systems that are gaining farmer acceptance. NT is a relatively new practice that has undergone widespread adoption in many maize producing regions of the USA (9). Because it improves water infiltration (4) and increases soil porosity (12), NT can be expected to impact NO_3-N leaching, though often in ways that are not readily predictable (16). At the site being reported in this manuscript, where tile drains improved soil aeration (3), potential net nitrification activity was increased more by drainage with tile drains than potential net mineralization activity (5). And, both NH_4-N disappearance and NO_3-N production were significantly higher at most depths in drained plots than in undrained plots. Cover cropping with non-leguminous winter annuals, such as rye (*Secale cereale* L.), is an old practice with great potential for renewed use. Not only does rye help control soil loss during otherwise fallow winter periods, use of a rye cover crop may significantly reduce NO_3-N leaching during the fall, winter and early spring (1). Similar results were more recently found for Italian ryegrass (*Lolium perenne* L.) (10). Research was undertaken to evaluate the effects of tillage (CT vs. NT) and winter cover cropping (F vs. R) on NO_3-N leaching from land devoted to maize production.

MATERIALS AND METHODS

Field Site

The study is located near Watkinsville, Georgia. The site is a Cecil sandy loam soil (clayey, kaolinitic, thermic Typic Kanhapludults), and consists of 12 instrumented, tile-drained plots, each measuring 10 m wide × 30 m long. A previous description of these plots is given (3). Drain tile were installed in six plots during October 1981 and during September 1990 in the remaining six plots. To exclude subsurface lateral flow, plot borders are enclosed with polyethylene sheeting to a depth of 0.9 m. Water volume drained from a plot was measured by a tipping bucket and recorded with a datalogger. A small portion of the drainage flow (<3%) is removed by a sampling slot located between tipping-bucket halves. Drainage samples from each plot were collected and stored under refrigeration (1.7°C) in the field by an ISCO Model 3700 FR sequential waste water sampler (ISCO, Inc., Lincoln, NE 68501-2531). Drainage samples were analyzed for NO_3-N by the Griess-Ilosvay method (8), following reduction by Cd to NO_2-N.

Field Operations, Sampling, and Analysis

Dates of field operations and sampling and cultural details are given in Table 1. CT maize was grown during the summer of 1991 on all plots and following grain harvest maize stalks were shredded. Six plots were selected for R throughtout the study and planted on 18 October 1991. The remaining six plots were used for F. The soil profile was sampled to 0.90 m in 15-cm increments to assess the soil inorganic N content. Soil samples were extracted with 2 *M* KCl (20 g soil:100 mL solution), and soil extracts were analyzed for NH_4-N by the indophenol-blue method (8) and for NO_3-N by the Griess-Ilosvay method (8). To estimate dry matter production and N uptake by rye and maize, above ground tissue samples were taken. Samples were dried, ground, and digested (11). Nitrogen concentrations were determined colorimetrically by the indophenol-blue reaction (8). Prior to maize planting rye was killed and tillage treatments were imposed. CT plots were mowed, moldboard plowed and disked; and NT plots were mowed, sprayed with paraquat and left untilled. Fertilizer N was broadcast following maize planting. In 1992, because of extensive bird damage to seedling stand, maize on the NT winter cover plots was replanted. Atrazine and alachlor were sprayed following maize planting for weed control. Maize grain was hand harvested for yield measurements, and corn stover samples were taken following mechanical harvesting of grain from the two center rows of each plot.

Experimental Design and Statistical Procedures

The experiment was laid out as a split plot design in randomized blocks with three replications. The main plot is tillage (CT or NT), and the subplot is R or F. Analysis of variance was performed using SAS (SAS Institute, 1985).

Table 1 Field operations, and plant and soil sampling dates.

Activity	1991 CT	1991 NT	1992 CT	1992 NT	1993 CT	1993 NT
	------------Tillage------------					
	-------Dates (day/month)-------					
Maize Fertlizing[1]	1804	1804	2404	2704	2004	2004
Herbicide[2]	----	----	----	2204⁺	----	1304⁺
Tilling:						
Spring[3]	1704	1704	2304	----	1204	----
Fall	1810	----	3010	----	2409	----
Maize Planting[4]	2204	2204	2404	2404	1404	1404
Herbicide-post	2204	2204	2804	2804	1404	1404
Maize Harvesting	1109	1109	0710	0710	1409	1409
Shredding						
Maize	0410	0410	2910	2910	1409	1409
Rye	----	----	2304	2304	1204	1204
Rye Planting[2]	1810	1810	3010	3010*	2909	2909
Soil Sampling[5]						
Spring	----	----	2304	2304	2004	2004
Fall	0611	0611			1008	1008
Plant Sampling:						
Maize	0911	0911	1607	1607		
	----	----	0710	0710	1509	1509
Rye	----	----	1501	1501	1401	1401
	----	----	1402	1402	1202	1202
	----	----	1203	1203	1603	1603
	----	----	2304	2304	1204	1204

[1]168 kg-N ha^{-1} as NH_4NO_3.
[2]Paraquat(⁺) (1,1′-dimethyl-4,4′-bipyridinium ion), or glyphosate(*) N-(phosphonomethyl) glycine.
[3]CT were shredded moldboard plowed and disked and NT were shredded. Both CT and NT plots were CT in 1991.
[4]Planted with a coulter followed by double disk openers in 0.76 m row spacing and 60 250 kernels ha^{-1}, cv. DeKalb 689.
[5]Sampled to 0.90 m in 0.15-m increments.

RESULTS AND DISCUSSION

Drainage from the soil profile occurs when precipitation exceeds evaporation. In the Southeastern USA drainage normally occurs during the months of November, December, January, Februrary, and part of March. Infrequently wet summers occur and precipitation exceeds evaporation. Drain tile effluent measurements began the winter of 1991-1992. Rainfall this first winter was below average (Table 2). Nitrate concentration in the cummulative drainage for the 1991-1992 R plots was about half the approximately 22 ppm of the F, Figure 1. Maize planted April 1992 was the first maize crop with all treatments fully functioning. June through September 1992 rainfall exceeded the longterm average (Table 2) and plot drainage (Figure 2) occured. Drainage started about 9 June and continued periodically through the summer and fall. Between the first drainage event and until approximately 100 mm of

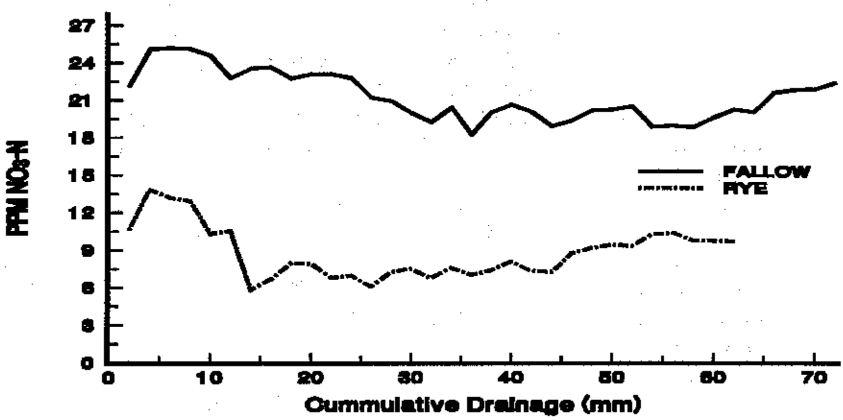

Figure 1: Nitrate concentrations and cummulative drainage from fallow and rye plots during the 1991-1992 winter.

Table 2 Monthly Rainfall from October 1991 through October 1993, and Deviation from Long-Term (1884-1991) Average Monthly Rainfall at Watkinsville, Georgia.

Month	1991 Monthly	1991 Deficit(-) Surplus (+)	1992 Monthly	1992 Deficit(-) Surplus (+)	1993 Monthly	1993 Deficit(-) Surplus (+)
	mm					
January			88.2	-30.1	94.9	-24.0
February			121.9	+1.3	149.1	+28.5
March			101.6	-32.8	185.7	+51.3
April			40.1	-58.5	74.4	-24.2
May			43.7	-52.8	56.4	-40.1
June			165.3	+66.0	19.1	-80.2
July			145.1	+18.4	49.9	-76.8
August			205.5	+98.1	29.6	-77.8
September			194.3	+108.7	79.3	-6.3
October	3.4	-72.3	61.7	-14.0	110.7	+35.0
November	17.0	-60.9		-61.0	202.5	-124.5
December	81.5	-29.0			133.6	+23.1

drainage occured NO_3-N concentrations were greatest from the NT plots, and subsequently NT and CT were not different. The 1992-1993 winter NO_3-N concentrations in the drainage water were significantly higher for CT F. The higher concentration CT F NO_3-N drainage occured from the first week of January and through the first week of March, Figure 3. Maize yields for 1991 were about half the 1992 6.7 Mg ha^{-1} maize grain yield. The larger 1992 maize plant biomass production effectively reduced all the winter 1992-1993 R and F NO_3-N drainage concentrations to about half that for the R and F of winter 1991-1992. Only the CT F plots lost during the 1992-1993 winter months significantly more total NO_3-N. Winter 1992-1993 dry matter yields for NT R and CT R were 0.94 and 1.38 Mg ha^{-1}, respectively; and the N uptake for NT R and CT R was 17.7 and 26.2 kg ha^{-1}, respectively. Both dry matter yields and N uptake values were significantly different at the 5% level.

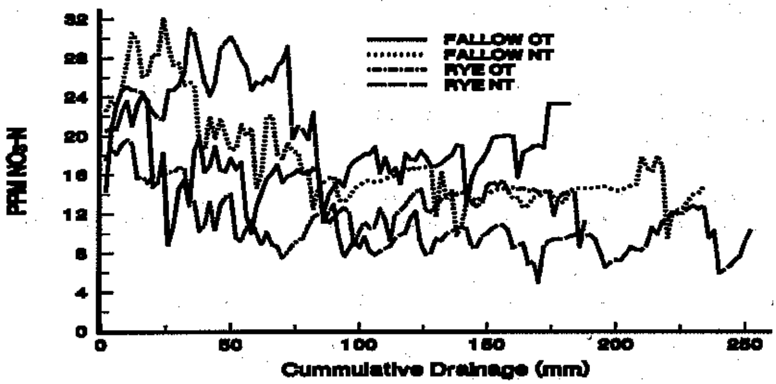

Figure 2. Nitrate concentration and cummulative drainage for the summer of 1992 from CT and NT plots with either R or F winter treatments.

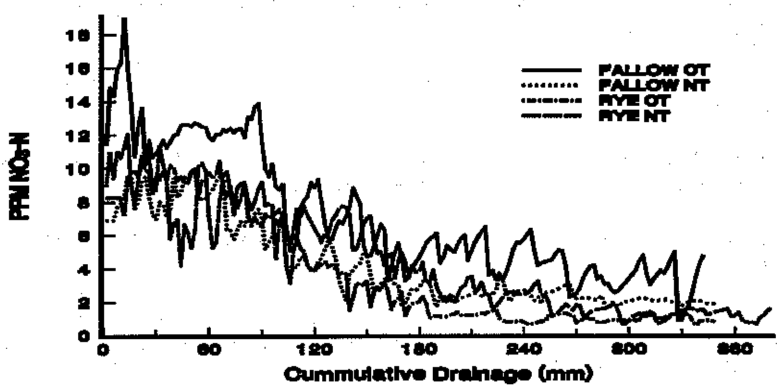

Figure 3. Nitrate concentrarion and cummulative drainage, 1992-1993 winter, from the CT and NT plots with R or F treatments.

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INFLUENCE OF DIFFERENT CATCH CROPS AND PLOUGHING TIMES ON SOIL MINERAL NITROGEN

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ABSTRACT

The influence of catch crops on the accumulation of mineral nitrogen (ammonium and nitrate N) in soil during autumn and winter was studied in 22 field experiments in south and central Sweden during 1989-92. Four catch crop treatments (red clover, white clover, perennial rye grass and a red clover-perennial rye grass mixture, all undersown in spring barley), were compared with a treatment without a catch crop. Ploughing was carried at three different times: in early autumn (average date: 6 October), in late autumn (average date: 26 November) and in early spring (average date: 25 March). In seven of the experiments the effects of catch crops on the subsequent crop, spring barley, were studied. At two of these seven sites, with heavier soils, spring ploughing was replaced by shallow tillage in spring.

The catch crops reduced the grain yield of spring barley in the first year by, on average, 1-3%. At yellow ripeness of this barley crop, 41 kg ha^{-1} of mineral N remained within the 0-90 cm soil layer as an average for all treatments with and without a catch crop. In late November the average total nitrogen contents in the above-ground parts of the red clover, white clover and rye grass catch crops amounted to about 25 kg N ha^{-1}, whereas the red clover-rye grass mixture had taken up 32 kg. However, there were large variations in total N contents between sites.

The clover catch crops and the red clover-rye grass mixture increased the nitrogen supply to the barley in the second year by 30-40 and ca. 15 kg N ha^{-1}, respectively, compared with the treatment without a catch crop. Pure rye grass had only a small or no additional N effect. The nitrogen effects were mainly due to increased net N mineralization during the growing season of the second year. After autumn ploughing, the three clover-containing catch crops increased grain yields of barley by, on average, 10-16%. After pure rye grass, the yield increase was 9%. Spring ploughing, or shallow tillage on heavier soils, caused reduced yields, especially after rye grass and after the red clover-rye grass mixture, compared with ploughing in late autumn.

INTRODUCTION

In cultivation systems in Sweden with annual crops such as spring cereals, the soil has a crop cover only during late spring and in the summer. This implies that nitrogen in the soil is utilized by the crops merely for 3-4 months. Nitrogen mineralization during the rest of the year seems to largely influence nitrogen leaching (Torstensson et al., 1; Lindén et al., 2). In order to minimize N leaching by counteracting the accumulation of mineral nitrogen in the soil during the rest of the year, as influenced by N mineralization and, to some extent, by residual fertilizer nitrogen, crops can be established which take up nitrogen during the autumn and, if possible, also during mild winter periods. For this, regulations have been introduced in Sweden concerning the cultivation of such crops. Autumn-sown cereals and oilseeds, leys, etc., may be used for this purpose. Farmers in south Sweden must cultivate up to 60% of their acreage with such "autumn/winter cover crops". However, if this cannot be fully achieved by means of the ordinary crops, cultivation of certain catch crops are required, grown merely to utilize and tie up nitrogen biologically during the cold season. In the present investigation, the effects of different undersown catch crops on the yield of the main crop and on leachable soil mineral nitrogen during the cold seasons were studied in 22 field experiments in south and central Sweden. In seven of these trials also the after-effects during the subsequent growing season were investigated.

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MATERIAL AND METHODS

During the first year, spring barley was cultivated as main crop with and without undersown catch crops as follows:

A. Without a catch crop and with stubble tillage after the harvest
B. Red clover (seed rate: 8 kg ha^{-1})
C. White clover (seed rate: 5 kg ha^{-1})
D. Perennial rye grass (seed rate: 10 kg ha^{-1})
E. Red clover and perennial rye grass (seed rates: 3 and 9 kg ha^{-1})

The treatments were replicated three times but only twice in the seven trials remaining during the second growing season. The barley was fertilized with 80 kg N ha^{-1}. After the harvest the straw was removed. Then the plots of the treatments A-E were divided into three subplots, which were ploughed at one of the following three times:

- in early autumn (average date: 6 October), except plots B, C and D
- in late autumn (average date: 26 November)
- in early spring (average date: 25 March)

In the experiments on heavier soils, spring ploughing was replaced by shallow tillage with a disc-tiller or cultivator. In the seven experiments remaining during the growing season of the second year, the effects of the catch crops on the nitrogen supply and grain yield of spring barley were studied. For this, all subplots were divided into two parts and fertilized in spring with 0 and 80 kg N ha^{-1}, respectively.

In order to elucidate the nitrogen conditions in the soil as influenced by catch crops and ploughing times, soil samples for determination of mineral nitrogen (ammonium and nitrate nitrogen) were taken from the 0-30, 30-60 and 60-90 cm layers at four times (see Tables 3, 4 and 5). For determination of crop uptake of nitrogen from the soil during the growing season of the second year, the subplots without nitrogen fertilization in that year, called N_0 plots, were used. For this, the crop was cut at the soil surface at yellow ripeness (average date: 4 August). It was assumed that the nitrogen content in the roots was 25% of that in the whole plant. The plant-utilized fraction of the mineral nitrogen present in the soil in early spring was calculated as the difference between the amount of mineral nitrogen in early spring and that in the N_0 plots at yellow ripeness. For calculation of net nitrogen mineralization during the growing season, the following formula was used:

$$N_{net} = N_c + N_{un} - N_{spr}$$

where N_{net} = net mineralization of nitrogen (more precisely: net gain of nitrogen)

N_c = crop uptake of nitrogen in N_0 plots until yellow ripeness (= plant-utilized soil nitrogen)

N_{un} = mineral nitrogen within the 0-90 cm soil layer in the N_0 plots at yellow ripeness (= unutilized mineral nitrogen)

N_{spr} = mineral nitrogen within the 0-90 cm soil layer in early spring before the start of the growing season.

The average temperatures, especially during the cold season were generally higher than normal. During the winters, the soils were not frozen or frozen only superficially and for short periods, which contrasts to normal winters, especially in central Sweden.

RESULTS AND DISCUSSION

The undersown catch crops had little influence on the grain yields of spring barley <u>during the first year</u> (Table 1) with, on average, only 1-3% lower production than without a catch crop. The average above-ground production of the catch crops until late autumn (average sampling date: 20 November) is shown in Table 1. There were large variations in N contents between trials, from almost nothing or a few kg N ha^{-1} to 55 kg in the rye grass and still more in the clover-containing catch crops. The growth and N uptake of the catch crops seemed to be largely dependent on the establishment of these crops during summer as influenced by weather conditions and by competition with the main crops.

Table 1. Average grain yields of spring barley (15% moisture content) in the first experimental year and average DM production and total nitrogen content of above-ground parts of undersown catch crops sampled in late autumn of the first year. The values within brackets refer to minimum and maximum amounts of total N. Means of 22 trials

		Yield of barley		Catch crop	
		kg/ha^{-1}	rel.	DM, kg/ha^{-1}	Total N, kg/ha^{-1}
A	Without a catch crop	5 250	100	-	-
B	Red clover	5 140	98	940	26 (3-90)
C	White clover	5 190	99	760	23 (<1-79)
D	Perennial rye grass	5 160	98	1 040	24 (4-55)
E	Red clover + perennial rye grass	5 070	97	1 320	32 (5-68)

Table 2. Grain yields in spring barley (kg ha^{-1}, 15% moisture content) during the second experimental year and after different catch crops. Means of 7 trials

		Ploughing time		
		Early autumn	Late autumn	Early spring
A	Without a catch crop	3 710	3 990	3 900
B	Red clover	-	4 620	4 120
C	White clover	-	4 400	4 190
D	Perennial rye grass	-	4 350	3 320
E	Red clover + perennial rye grass	3 980	4 520	3 640

The influence of the catch crops on grain yields of spring barley <u>in the second year</u> in relation to the three ploughing times is shown in Table 2. Ploughing in late autumn of the first year led to the highest production, both with and without catch crops. After ploughing in late autumn, the red clover, white clover and the red clover-rye grass mixture increased grain yields by 16, 10 and 13%, respectively, compared with the treatment without a catch crop. After the pure rye grass catch crop, the average yield addition was 9%.

At yellow ripeness in the first year, in late July–early August, the amounts of mineral nitrogen within the 0-90 cm soil layer averaged 41 kg ha^{-1} for all treatments. The catch crops had no statistically significant influence on these amounts (Table 3), which can be considered unutilized residues left by the barley at the end of N uptake.

With rye grass and the red clover-rye grass mixture as catch crops, the amounts of mineral N remained the same or decreased somewhat from late summer to the sampling in late autumn (average date: 20 November) in the soil still not ploughed, see Table 3. In the treatments with clover and without a catch crop, mineral N increased by ca. 10 kg N ha^{-1}. However, after ploughing in early October the amounts increased still more in soil without a catch crop and especially after the red clover-rye grass mixture. The amounts of mineral nitrogen in late autumn varied considerably between sites. For instance, whereas the average amount was 36 kg N ha^{-1} in the rye grass plots before ploughing in late autumn, the minimum value was ca. 10 kg and the maximum 149 kg. The larger amounts in several of the trials indicate that the rye grass could not reduce the amounts of leachable nitrogen satisfactorally in all cases. In the treatments left unploughed until early spring, mineral N levels remained rather unaltered during the winter period, still with the lowest values in the rye grass and red clover-rye grass plots (Table 4).

Table 3. Average amounts of mineral nitrogen (kg ha^{-1}) in the 0-90 cm soil layer during the first experimental year: at yellow ripeness of the main crop (average sampling date: 6 August) and in late autumn (average sampling date: 20 November)

		Catch crop				
Year	Number of observations	A Without a catch crop	B Red clover	C White clover	D Perennial rye grass	E Red clover and perennial rye grass
Yellow ripeness						
	21	44	44	43	38	38
Late autumn						
After ploughing in early autumn:						
	20	59	-	-	-	50
Soil still not ploughed at sampling:						
	22	55	52	54	36	36

In treatments without a catch crop, the spring barley in the second experimental year utilized about 70 kg ha^{-1} of soil nitrogen, irrespective of ploughing time (Table 5). Similar amounts of plant-available nitrogen were recorded after the rye grass, but as much as, on average, 98-110 kg was obtained in the different treatments with the pure clover catch crops. The share of these nitrogen supplies originating from mineral nitrogen present in the 0-90 cm soil layer in early spring was generally small, especially after ploughing or shallow tillage in spring. Following ploughing in late autumn, on average 14 kg ha^{-1} of mineral N was utilized after rye grass and somewhat more in the other treatments.

Net nitrogen mineralization during the growing season of the second year, constituting a contribution to the total crop uptake of soil nitrogen, amounted to 56 kg N ha^{-1}, on average, after ploughing plots without a catch crop in late autumn (Table 5). Similar amounts were obtained for the other ploughing times. The catch crops obviously influenced net nitrogen mineralization positively, with the largest additions (23-39 kg N ha^{-1}) after the red and white clover and the smallest increases, generally only a few kg N ha^{-1}, after pure rye grass. After the red clover-rye grass mixture, ca. 15 kg more nitrogen was released than without a catch crop. The ploughing times showed no distinct influence, but ploughing in early autumn seemed to reduce the release of N during the subsequent growing season.

Table 4. Mineral nitrogen (kg ha^{-1}) in the 0-90 cm soil layer in early spring of the second experimental year (average sampling date: 2 April) after ploughing catch crops early or late in the autumn (average ploughing dates: 6 October and 20 November, respectively) compared with soil still not ploughed in early spring

Year	Number of observations	Catch crop A Without a catch crop	B Red clover	C White clover	D Perennial rye grass	E Red clover and perennial rye grass
After ploughing early during the preceding autumn:						
	22	68	-	-	-	66
After ploughing late during the preceding autumn:						
	22	64	74	74	59	64
Soil still not ploughed at sampling:						
	22	57	58	57	37	40

Table 5. Soil nitrogen in the N_0 plots utilized by the barley during the growing season of the second experimental year after the different catch crops

Ploughing time	Catch crop A Without a catch crop	B Red clover	C White clover	D Perennial rye grass	E Red clover and perennial rye grass
Early autumn	70	-	-	-	86
Late autumn	75	105	110	81	90
Early spring a)	66	105	98	62	75
Number of observations	7	7	6	7	7

a) Shallow tillage on loam and clay soils (n = 2).

CONCLUSIONS

Without a catch crop, the amounts of mineral nitrogen within the 0-90 cm soil layer increased by, on average, 11 kg N ha^{-1} from yellow ripeness in late summer until ploughing in November in the first year, but somewhat more after ploughing in early October. As some N losses may have occurred during this period, net nitrogen mineralization should have been larger. The amounts of mineral nitrogen generally remained low or even decreased until late autumn in the treatment with ryegrass still not ploughed in November. The nitrogen found in the rye grass, on average 32 kg N ha^{-1}, was equivalent to about 20 kg ha^{-1} less mineral nitrogen in soil at this time compared with the treatment without a catch crop. In the latter case, mineral nitrogen generally moved down to the subsoil layers during autumn, whereas the amounts in these layers mostly remained low or even decreased in the rye grass treatment. In accordance with the findings of, e.g., Schjørring et al. (3) and Lindén et al. (4) this catch crop therefore must have reduced N leaching during autumn. A corresponding effect seems to have been exerted by the red clover-rye grass mixture. However, the clover catch crops generally did not reduce mineral N levels. Thus red and white clover should have been inferior alternatives to rye grass (cf. Schjørring et al., (3) & Beck-Friis et al., (4) and to the red clover-rye grass mixture in reducing the risk of N leaching in autumn. Despite the large potential growth and N uptake, the variations in these respects between trials, with only a few kg N ha^{-1} in the above-ground parts of the catch crops in several experiments, indicate that it cannot be taken for granted that catch crops, including rye grass, effectively reduce N leaching under all circumstances.

After ploughing in early and late autumn the amounts of mineral N increased until early spring in the treatment without a catch crop as well as after the catch crops. As nitrogen losses must have occurred to varying extents, net mineralization during the winter period should have been larger than these increases. The smaller amounts of mineral nitrogen in spring in all treatments left unploughed during winter indicate reduced risks of N leaching. Ploughing rye grass and the red clover-rye grass mixture in early or late autumn must have been somewhat less effective against leaching. The accumulation of mineralized nitrogen during the winter indicates that ploughing the red and white clover catch crops in autumn constituted the largest potential risk of N leaching, probably larger than without a catch crop under conditions with mild winters. Therefore, it seems doubtful whether these plants should be grown as catch crops if they are ploughed in autumn. This may also include incorporation into the soil in spring, as there was no reduction of mineral N compared with the treatment without a catch crop and thus probably no general reduction of nitrogen leaching.

In order to reduce N leaching effectively, it seems necessary to use rye grass as a catch crop or, alternatively, a clover-rye grass mixture. However, incorporation of these catch crops into the soil in spring led to yield decreases, especially on loam and clay soils where shallow tillage was used. Shallow tillage in spring on these soils was inappropriate as the rye grass was incompletely killed and incorporated into the soil. As rye grass ploughed in late autumn increased the grain yields of the subsequent barley crop compared with the treatment without a catch crop, it seems to be an appropriate compromise between leaching and yield aspects to plough rye grass in late autumn, at least on loam and clay soils and in regions with colder winters. The same may be valid for the red clover-rye grass mixture.

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PESTICIDE AND NITRATE TRANSPORT THROUGH A SILT LOAM SOIL INTO SUBSURFACE TILE DRAINS

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ABSTRACT

Subsurface tile drains are useful tools for measuring field-scale transport of chemicals below the rootzone. The objectives of this study were to determine field-scale pesticide and nitrate leaching losses from a low organic matter, poorly structured silt loam soil under chisel tillage practices and three different drainage intensities. Two replicates each of three subsurface drain spacings (5, 10, 20m) are instrumented to measure drain discharge rates and to collect drainflow samples on a flow-proportional basis. Chemical concentrations and mass losses are determined as a function of time and net water drainage. Data has been collected since 1985. Most of the pesticide losses in tile outflow occurred as pulses of chemical with each storm event within the first two months after chemical application, with very few pesticide detections occurring during the majority of the year. These findings are consistent with preferential flow concepts. Nitrate-N losses occurred throughout the year and averaged about 40 kg N ha^{-1}.

INTRODUCTION

The contamination of groundwater and surface water by agricultural chemicals has become an international concern. There is a critical need for field-scale data on chemical transport through soils under a variety of soil and climatic conditions. The overall objective of this study is to quantify pesticide and nutrient losses from the rootzone into shallow groundwater (tile drainage water), on a low organic matter silt loam soil under typical agricultural management practices. Specific objectives are: 1) determine pesticide and nitrate-N concentrations and mass losses in tile drain outflow, as a function of time during the year and tile drain spacing, and 2) measure field-scale preferential flow of pesticides and a non-sorbed tracer (bromide).

METHODS

A detailed description of the field site, crop and chemical management, and laboratory methodology is given in Kladivko et al. (1). Briefly, the field site is located in southeastern Indiana USA on a Clermont silt loam soil (fine, silty, mixed, mesic, Typic Ochraqualf). The soil is low in organic matter, poorly structured, slowly permeable, and has a borderline fragipan at a 120 cm depth. Subsurface plastic drains (10 cm diam.) were installed in 1983 at an average depth of 75 cm and spacings of 5, 10 and 20 m in two replicates each of plots 225 m long. Water samples are collected automatically on a flow-proportional basis, and chemical concentrations and mass losses are determined as a function of time and net water drainage. Corn (Zea mays L.) is grown each year, and chemicals applied yearly include nitrogen (285 kg N $ha^{-1}y^{-1}$ through 1988, 228 kg N $ha^{-1}y^{-1}$ starting 1989), carbofuran, atrazine, and cyanazine (1.5, 1.1, and 2.3 kg A.I. $ha^{-1}y^{-1}$, respectively). Alachlor (2.3 kg A.I. $ha^{-1}y^{-1}$) was applied in all years except 1989 and 1990. In addition, a one-time application of bromide and simazine was made, to determine the breakthrough for a conservative tracer and pesticide simultaneously. Potassium bromide and simazine were applied to a 3-m wide strip, offset 1.5 m east of the center tile drain in two plots (10 m and 20 m spacings, Block 2). This application was made in late autumn (20 November 1989), at the start of the annual winter leaching period.

RESULTS AND DISCUSSION

Pesticides

Small amounts of pesticides were detected in tile outflow much sooner than predicted by standard convection-dispersion theories of chemical transport. Pesticides were already detected in the first storm after application (Fig. 1), with less than 1 cm net drainage from the soil (one pore volume for this system is about 30 cm drainage). All three (or four) pesticides arrived at the drain at the same time, in spite of differences in equilibrium sorption coefficients. This early arrival of all chemicals is consistent with concepts of preferential flow and non-equilibrium sorption/desorption.

Pesticide transport was event-driven, with peak concentrations occurring at the start of each new drainage event (Fig. 1). Concentrations dropped rapidly as the event continued. Generally, peak concentrations decreased during the season with each new drainage event. The third storm in 1989 was an exception, showing much higher concentrations than in the first storm. The magnitude of the peak concentrations appears to be a function of several environmental variables including storm size, time period between storms, time period between chemical application and the first drainage event, and occurrence of small storms that do not produce drainflow. These interactions are being further assessed in laboratory experiments.

Although the timing of pesticide losses did not depend on sorption coefficients, generally the rank-order of total mass losses and concentration ranges did correspond with the rank-order of pesticide sorption coefficients. Thus carbofuran had the greatest losses (as a % of applied), followed by atrazine, cyanazine, and finally alachlor. Four-year average annual mass losses for carbofuran, atrazine and cyanazine for the three drain spacings are shown in Table 1. As expected, the narrowest drain spacing (more intensive drainage) had greater relative losses of water and pesticide than did the widest drain spacing.

There was little detectable pesticide in drainage outflow during fall, winter, and early spring. Thus almost all pesticide mass losses to tile drainage occurred during the first 2 months after application, whenever there was a large enough storm to produce tile flow. Although the overall drain flow during this 2 month period is relatively small (see Table

1), it is important for pesticide leaching. This suggests that for this and similar soils, research and management efforts should be focused on minimizing this early movement or preferential flow, because the remainder of the year contributes very little to total mass losses of pesticides.

Bromide and Simazine

Bromide and simazine reached the tile drain after <1 cm total net drainage from the soil. This occurred even though these chemicals were not applied directly over the draintile and old trench. The data support the interpretation that preferential flow is occurring in the field as a whole and not just in the part of the field disturbed during tile installation.

During the first 25 days of 1990, bromide and simazine tended to show peak concentrations at the same time, roughly corresponding with the beginning of each water peak. After greater times, however, bromide peaks tended to be offset in time from the simazine and water peaks, as expected for a non-sorbed tracer as it becomes more distributed throughout the soil matrix. This is clearly evident by planting time, 1990, as both bromide and nitrate concentrations dropped when water flow peaked during each event (in contrast to pesticide behavior illustrated in Fig. 1).

Nitrate

Annual nitrate-N losses to subsurface drains have ranged from 18 to 70 kg N ha^{-1}, varying with year, drain spacing, crop yield, and total drainflow. Nitrate-N concentrations in drainflow were generally in the 20 to 40 mg N/liter range. As with the pesticides, the narrower drain spacings removed more nitrate-N per unit area than did the wider drain spacings. Average annual nitrate-N losses to the tile drains from the 20 m spacing plots have been about 30 kg ha^{-1}, except in 1988-89 when losses were about 50 kg ha^{-1}, probably due in part to low corn yields in 1988 (and therefore more residual N in the soil). In contrast to pesticide losses, most nitrate-N losses to tile drains occur during fall, winter, and early spring when most of the water flow occurs.

CONCLUSIONS

Pesticide transport in this soil occurred mostly as preferential flow during the first two months after application. Nitrate transport via bulk convection occurred throughout the year, and preferential flow was probably of minor significance for this compound. These data reinforce the idea that nitrate leaching management and pesticide leaching management are completely separate issues on many soils, and that strategies to minimize pesticide losses in spring may have little effect on total annual nitrate losses.

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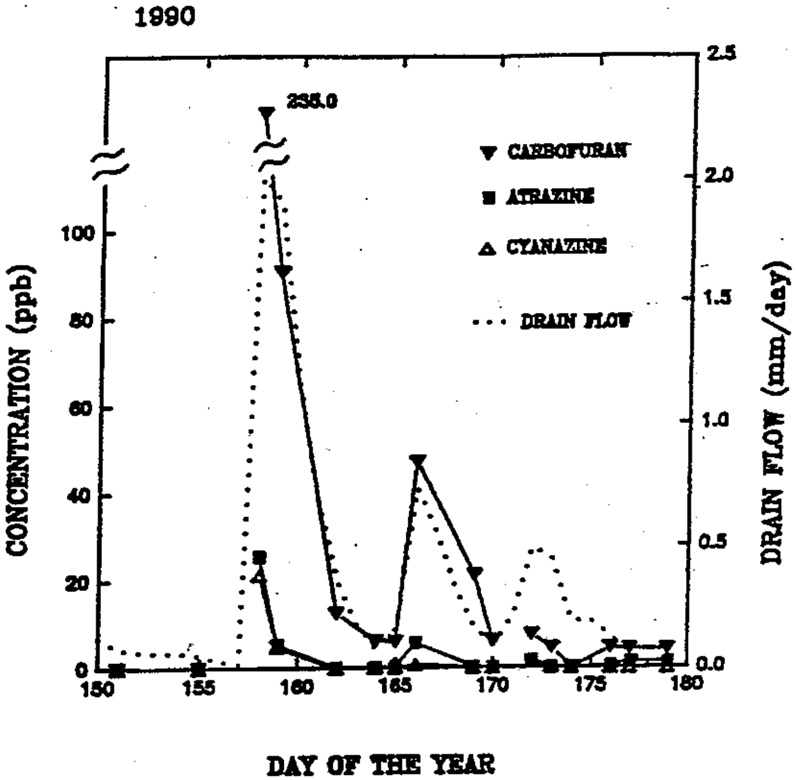

Fig. 1. Tile drain outflow and pesticide concentrations from the 20 m spacing, Block 2, from day 150 to 180, 1990. (Planted on day 151).

Table 1. Average annual subsurface drainage losses during 2 months after planting (4 year average).

	5m	10m	20m
	------ Pesticide loss (%) ------		
Carbofuran	0.45	0.44	0.12
Atrazine	0.08	0.05	0.04
Cyanazine	0.04	0.02	0.02
	-------- Drainage (cm) --------		
Water	1.57	0.98	1.28

EFFECT OF LONG-TERM MANURE APPLICATION ON EARTHWORM MACROPORES AND PREFERENTIAL TRANSPORT THROUGH A LOESS SOIL

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ABSTRACT

This study quantified the effects of long-term application of liquid dairy manure and inorganic fertilizer on number and size distribution of earthworm macropores and their relationship to preferential transport of water and tracer through undisturbed large soil cores. Visible surface macropores were continuous to much deeper depth in soil columns taken from manure than from the inorganic fertilizer plots. Identification of the earthworms a year later showed the presence of *Apporectodea tuberculata, A. trapezoides* and *Lumbricus rubellus,* geophagous species, as well as *L. terristris,* a detritivorous species in the manure applied plot. *A. tuberculata* was the only species present in the inorganic fertilizer plot. Number of macropores and macroporosity varied with soil depth. The maximum macroporosity was less than 2.5% and occurred at a 2 cm depth. The predominant macropore sizes were between 1-2 mm radii for both treatments. Inflow rate at 2 cm hydraulic head averaged over three columns for a given treatment was nearly the same for both treatments and corresponded to an average value of 137 cm day^{-1}. However during breakthrough experiments, chloride appeared earlier in soil columns taken from the manure plot thereby indicating a greater continuity of macropores in the manure compared to the inorganic fertilizer treatment.

INTRODUCTION

The mid-western karst region includes southeast Minnesota, northeastern Iowa, southwestern Wisconsin and northwestern Illinois. The soils of the area are loess driven soils and are moderately permeable when protected from surface sealing due to the direct impact of raindrops (1). In this region, groundwater contamination has been reported by several investigators (2, 3). Since soils are shallow and the dolomitic bed rock is fractured, it is suspected that some of the groundwater contamination may be due to preferential flow of water through soils.

It is widely recognized that macropores allow preferential transport of surface water and chemicals through the root zone to deeper depths. It is also well known that deep burrowing earthworm species are found in soils with a history of manure application (4). The goal of this study was to quantify the effect of long-term manure application on earthworm macropores and in turn their effect on preferential transport of water and chemicals in a typical soil of the upper mid-western United States where land application of manure is common.

MATERIALS AND METHODS

Six large (~30 cm diameter x 90 cm length) undisturbed soil cores were taken from experimental plots with a long history of liquid dairy manure (three cores) and inorganic fertilizer (three cores) application. These cores were then characterized for preferential flow by running breakthrough curves and macropore continuity by following the penetration of color thin latex paint. Columns 1-3 represent the inorganic N source treatment whereas columns 4-6 represent the manure treatment. Details on sampling procedures, breakthrough curve set-up and pore characterization are given in Munyankusi et al. (5). Briefly, the liquid dairy manure was applied at the rate of 88.9 kL ha^{-1} (192 kg N ha^{-1}) per year to one set of plots and inorganic fertilizer (191 kg N ha^{-1}) to another set of plots during spring for eight years starting in 1982. These plots were chiseled plowed every year in the spring.

Breakthrough curves were run at 2 cm hydraulic head with a $CaCl_2$ solution. Hydraulic head at the soil surface was controlled with a marriotte bottle set-up. Approximately one pore volume was passed through the column before terminating the breakthough run.

After the completion of breakthrough curves, soil columns were allowed to drain under gravity before macropore characterization. Macropore characterization (continuity and distribution) was done by following the penetration of colored thin latex paint in the soil column, by tracing the visible macropores on a clear plastic sheet with a permanent marker at a given depth and then by analyzing the traced pores on a Microtek color/gray scanner. Latex paint was followed by loosening the soil in 1 cm increments and then vacuuming the soil with a wet / dry vacuum cleaner. At each depth, a new color paint was used for newly visible macropores.

RESULTS AND DISCUSSION

Macropore characterization

The problem of quantifying the continuity of macropores and in turn their effect on water flow is divided into two parts: (a) continuity of surface macropores and (b) continuity of subsurface macropores.

Surface macropores

In general, the number of surface macropores that are continuous to deeper depths decreased with an increase in soil depth irrespective of N source. The surface macropores in the liquid dairy manure applied plot penetrated much deeper than the macropores in the inorganic fertilizer plot. Out of three columns taken from the manure plot, the surface macropores in two columns (columns 4 and 5) were continuous to depths of 65 and 70 cm. This difference in continuity between manure and inorganic fertilizer plots reflected the difference in earthworm species.

In the fall of 1991, earthworms were also collected during the excavation of two additional soil columns, one each in manure and inorganic fertilizer plots. In approximately the same volume of soil dug around the 30 cm diameter column to a depth of about 35 cm, the number of earthworms collected were 45 for the manure plot compared to 18 in the inorganic fertilizer plot. This count included the adult as well as juvenile earthworms. Because of the difficulty of identifying juvenile earthworms, they were incubated for 4 months. After incubation, the number of earthworm tallied were 24 for the manure and 11 for the inorganic fertilizer treatment. In the manure treatment 15 *A. tuberculata*, 5 *L. rubellus*, 3 *L. terrestris*, and 1 *A. trapezoides* were found whereas all 11 earthworms belong to the species *A. tuberculata* were found in the inorganic fertilizer treatment. Greater continuity of surface macropores in the manure plot (columns 4 and 5) reflected the presence of *L. terrestris*, a species known to burrow vertically to depths of 1 m or more (6). The average number of earthworm macropores at the soil surface was 1053 and 1096 macropores m^{-2} for the inorganic fertilizer and manure treatments, respectively.

Subsurface macropores

The data showed a bi-modal distribution of macropores in the soil profile. The first peak in the number of macropores occurred between 1 and 2 cm depth whereas the second peak occurred between 20 to 45 cm depth. At depths of 10 to 15 cm, the total number of visible macropores decreased. This decrease in the number of macropores, was presumed to be either due to the annual soil disturbance by chisel plowing (tillage depth) or due to the presence of a moldboard plow pan developed prior to this study. Except for columns 4 and 5, the data showed that macropores that start in the top 1 to 5 cm terminated between 10 to 15 cm depth (tillage depth). This termination in conjunction with the decrease in the total number of macropores at depths 10 to 15 cm indicated a lack of continuity in macropores above and below this depth.

On average, the maximum number of macropores occurred at 2 cm depth (2,082 macropores m^{-2} for the inorganic fertilizer treatment and 1,793 macropores m^{-2} for the manure treatment). The higher number of macropores at 2 cm depth could possibly be due to exposure of several openings in the same horizontal macropore during serial sectioning. These numbers are higher than what has been reported in the literature (7). Except for 70 cm depth, the total number of macropores at any given depth were statistically ($p = 0.05$) similar between the manure and inorganic fertilizer treatments. At 70 cm depth, number of macropores in the inorganic fertilizer treatment were greater than the manure treatment.

Macroporosity

To compare our results with existing studies (8,9,10,11), the cross-sectional area of visible macropores was converted to percent macroporosity. Macroporosity is defined as the area of visible macropores to the cross-sectional area of the soil column. In general, the macroporosity of the manure plot was slightly higher as compared to the inorganic fertilizer plot. The macroporosity at the soil surface for columns 1, 2 and 3 of the inorganic fertilizer plot was equal to 0.56%, 1.02%, 0.20%, respectively. Surface macroporosity of columns 4, 5 and 6 of the manure plot was 1.16%, 0.89% and 0.08%, respectively. Irrespective of the treatment, macroporosity at any given depth was never greater than 2.5%. This is comparable to some of the numbers used by other researchers in their simulation models 2.04% (11), average between 1 to 5% (10) and higher than 1% (12).

Macropore size distribution

To facilitate the comparison of macropore size distribution between inorganic fertilizer and manure treatments, all visible macropores at any given depth were grouped into three classes based on their pore radii i.e. <1, 1-2 and >2 mm radius pores. One to two mm radius macropores were dominant in all six columns. As expected, the pores belonging to 1-2 mm radius class were maximum at 1 to 2 cm depth. There was also a decrease in the number of 1-2 mm radii macropores at around the 10-15 cm depth.

Preferential flow

Inflow rates
The inflow rate for all six columns varied between 62 to 232 cm d^{-1}. On average, the inflow rate for the inorganic fertilizer treatment (131 cm d^{-1}) was slightly lower than that of the manure treatment (142 cm d^{-1}). Considering the number of surface macropores in these columns, these flow rates are low. Using Poiseuille's law, and assuming a unit hydraulic gradient, these inflow rates would correspond to flow through a tube with a radius between 0.725 and 0.740 mm or 4 to 5 tubes with a radius of 0.5 mm. This is considerably less than the number and size of macropores measured with the paint injection technique at the soil surface. This suggests that in-spite of continuous macropores observed (columns 4 and 5) with the paint injection technique, most of the visible macropores were not effective in conducting water to the bottom of the soil column.

Chloride breakthrough curves
Comparison of chloride BTCs in soil columns taken from long term inorganic fertilizer and manure plots showed a trend of earlier breakthrough for manured applied compared to inorganic fertilizer treatments. In general, the BTCs of chloride for various columns within each treatment were nearly similar. The earlier breakthrough of chloride in columns 4, 5 and 6 reflected an increased macropore continuity in the manure treatment. On average, it took about a 0.75 pore volume displacement of chloride solution in inorganic fertilizer columns to reach a relative concentration of 0.5 in the leachate. This was considerably higher than 0.2 to 0.4 pore volume displacement for manure treatment (columns 4, 5, and 6). Statistical analysis showed that pore volume needed to achieve a relative concentration of 0.5 in the outflow solution was significantly ($p = 0.05$) different between the manure and the inorganic fertilizer treatments. Inflow rates indicated no major effect of macropores on water or contaminant transport, however, breakthrough curves showed some bypass or preferential transport of surface applied solution through macropores.

Modeling implications
Almost all models in the current literature , are generally based on the combination of Richard's equation and some variation of Poiseuille's law. Richard's equation describes water flow through the soil matrix whereas Poiseuille's law accounts for laminar water flow through macropores.

Most of the models that describe the transport of water and contaminants in soil in the presence of macroporesthe require inputs of macropore size distribution and macroporosity at the soil surface. Several of these models (11, 12, 13) assume that visible macropores at the soil surface are continuous to deeper depths which implies that macropore size distribution and macroporosity is the same at all depths.
As is clear from the present study, characterization of surface macropores is not sufficient to describe the role of these pores on water and contaminant transport through soil. In fact, the majority of the visible macropores at the soil surface are not continuous to deeper depths. Most of the pores starting at the soil surface and deeper

depths are dead end pores and their contribution to water and contaminant transport will be localized at depths where they terminate. This suggests that (1) non intrusive techniques such as CT-scan at small increments be explored to characterize macropore continuity and (2) stochastic procedures be developed to account for the tortuosity of macropores from non-intrusive serial sectioning.

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MACROPOROSITY AND BYPASS FLOW POTENTIAL AS RELATED TO TILLAGE AND RESIDUE MANAGEMENT SYSTEMS

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ABSTRACT

Simulation modeling of water flow and solute transport has the most utility to make soil/site specific recommendation of practices to control non-point source pollution. Tillage systems had a consistent influence on saturated hydraulic conductivity and continuity between soil layers in a highly structured Mollisol used for corn (*Zea mays L.*) and soybean (*Glycine max L.*). Estimated mean pore-water velocity identified potential internal catchments for agrichemicals movement.

INTRODUCTION

Retention and activity of agrichemicals in the target zone depends on application method and spatial environment in the soil. In corn-soybean production (1), 40% of the herbicide and nearly 80% of the fertilizer is applied preemerge. Herbicides are often surface applied and incorporated with the same machine, and fertilizer is applied with a soil engaging tool that is shank mounted. Incorporated crop residue in conservation tillage systems is retained in the upper 10 cm; the target zone for herbicides is the upper 5 cm; fertilizers are usually placed below the incorporated residue (1). When moldboard plowing is used these soil environments are much different--the herbicide is not exposed to fresh crop residue and fertilizer applied with a soil engaging tool may or may not be exposed to fresh residue. Surface applied agrichemicals are vulnerable to entrainment in runoff (2) and macroporous leaching into an internal catchment (3,4); this potential is greatly reduced by incorporation. Bypass flow in this layered system depends on connectivity of the layers and macroporosity of both the Ap layer and subsoil.

Our objective is to discuss the spatial character of tillage incorporated materials, the layers of macroporosity for preferential flow in tillage - layered soils, and the overall continuity for macroporous flow and solute transport.

METHODS

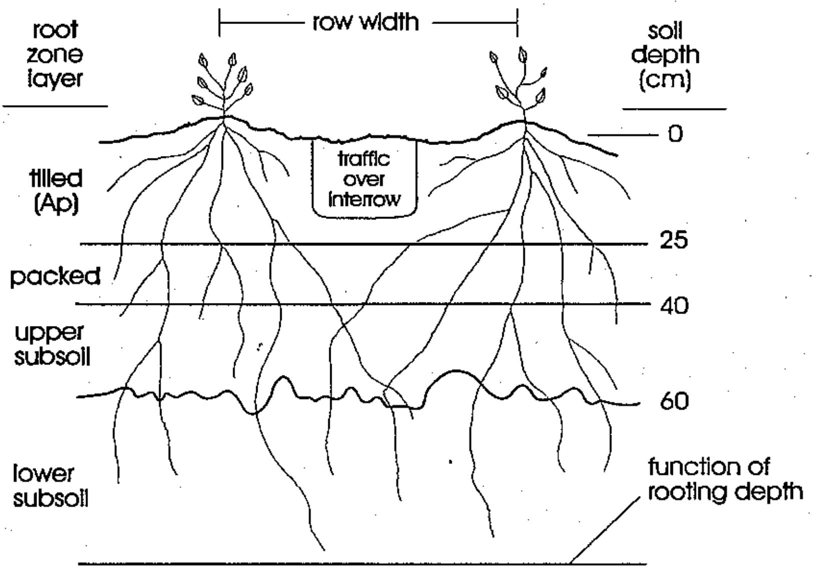
Spatial Character of Incorporated Materials

In a series of field experiments (5,6,7) on a Ves loam (mesic Udic Haplustoll), oats residues with tracer ceramic spheres and/or weed seeds were incorporated using different primary tillage tools. The tools tested were moldboard plow, disk, and chisel. From a series of 18-mm diameter cores, each 30 cm long and each sectioned into 2-cm increments, the soil porosity and contents of crop residue, weed seeds, and spherical tracers were measured in 5 cm³ volumes (18 mm diameter by 20 mm long). There were at least 60 cores spaced 4 cm center-to-center duplicated within each tillage treatment. The volumes were vertically contiguous, but spaced horizontally 4 cm center-to-center.

Macroporous Flow Systems in Layered/Tilled Soils

Saturated and unsaturated hydraulic conductivity (K_{sat}, K_{unsat}) measured with falling or constant head in undisturbed cores (8,9), tension infiltrometer techniques (9), depth function of bulk density, Br- breakthrough curves in undisturbed cores (10), macropore (>0.4 mm diameter) area (8), and dye movements (8) were each measured in a long-term tillage experiment on a Nicollet-Webster silty clay loam (mesic Aquic Hapludoll). The typical layered soil profile (11) was a reference guide for depths of measurement (Figure 1.). The Ap layer is usually subjected to rupture and packing annually and the depth varies depending on the primary tillage tool; the 25 to 40 cm subsoil layer is rarely ruptured but can be subjected to packing; the 40 to 60 or 80 cm upper subsoil layer usually contains biopores and cracks; and the lower subsoil below 60 or 80 cm usually is devoid of bioactivity and cracks due to wetting and drying.

Figure 1. Typical soil profile layered by tillage, traffic, and bioactivity.



RESULTS AND DISCUSSION

Spatial character of materials in Ap layer

Penetration of tillage tools (disk, chisel, moldboard plow) and oat residue incorporation patterns were tillage-tool specific (Figure 2). Operational depth was determined from bulk density profiles and depth of ceramic spheres incorporated simultaneous with oat residue (6). Incorporated mass of oat residue was <10% above 12 cm with the moldboard plow, >95% above 9 cm and a significant amount on the surface with the chisel, and >95% above 11 cm and only a small amount on the surface with the disk. Depth distribution of oat residue after chiseling was the same as that for untilled oat roots. Total buried residue was 1.6 times the shoot mass, and 95% of the root mass was above 10 cm (6).

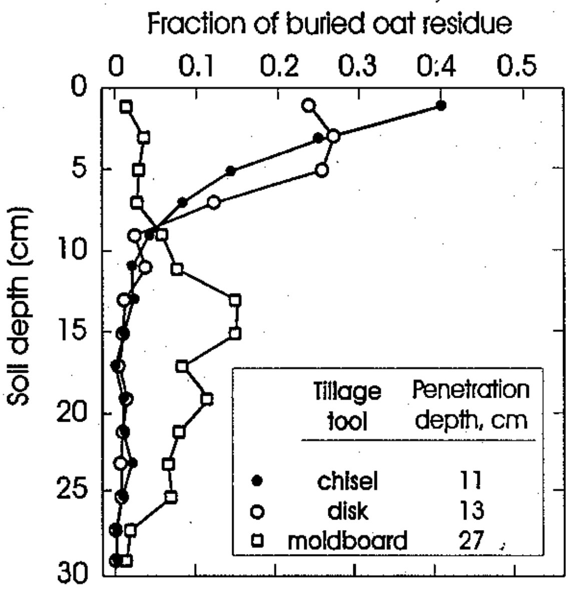


Figure 2. Tillage-tool penetration and depth distribution of incorporated oat residue.

On a macroscale (Figure 2), the crop residue was located in regions of low bulk density (6). On a microscale (5 cm^3 volumes), the oat residue in the vertical zone containing oat residue was highly clustered: (i) mean porosity of 5cm^3 volumes increased from an average of 0.53 to 0.57 cm^3/cm^3 when weighted according to mass of included oat residues, and (ii) histograms of residue concentration in 5cm^3 volumes were approximately exponential with many volumes without residue and only a small number with large concentrations of residue (6). Maximum concentrations of oat residue were 30 times greater than the mean concentration. Similar results in two different years indicates that the incorporation process is not a dispersal. All three tillage tools produced the same microscale characteristics in the zone of buried residue, spheres (as surrogates for pesticide granules or weed seeds) incorporated from the surface with the oat residue had the same macroscale and microscale characteristics as the residue.

Pore connections and interaggregate spaces were estimated especially those connected to the surface and containing one or more ceramic spheres. A 5 cm^3-volume with a porosity >0.50 cm^3/cm^3 was assumed to contain a connective pore. Aggregates > 12 mm diameter made up about 50% of the bulk volume (7), thus the 20 mm space between adjacent cores was assumed to have two spaces each of which took on the properties of it's adjacent 5 cm^3 volume. Roughly 35% of the volumes in the chisel and moldboard treatments were convective with 75% of these open to the surface. Only 20% of the pores in the untilled (since oat planting) soil were convective but 90% of these were open to the surface. Of the convective pores open to the surface 73% and 99% contained a granule surrogate in the moldboard plow and chisel tillage, respectively. Maximum length of convective pore was 26 and14 cm in these respective tillages.

When incorporated by one tillage pass, 99% of the oat residue and ceramic spheres were lodged into packing voids between aggregates; with additional tillage, incorporation rate into the aggregates was asymptotic with 3, 32, 50, and 58% of the original inert spheres incorporated after the first through fourth annual primary tillages, respectively (7). The incorporation rate into aggregates was as much as 10 years slower in the 3 to 5 mm compared to the 3 years in 40 mm aggregates.

Macroporous system for water flow and solute transport

Macroporosity and continuity between layers are summarized by K_{sat} (Table 1) and dye tracing. In both annual tillage and no tillage systems, all K_{sat} indicate macroporosity in both layers; Information in (8) was used to separate K_{sat} into matric and macropore components (13). For this silty clay loam, K_{sat} without the macropore component (13) was in the 1 μm/s range, which agrees with K_{sat} measured in the 22 to 28 cm plow pan and in severely compacted layers of this soil. Dye tracing (8) revealed a tillage pan-type structure in the annually tilled but not in the no-till or ridge-till system, through which dyes did not pass when released in the Ap layer. In the 40 to 80 cm depth within this Mollisol, preliminary measurements indicate K_{sat} in the 10 μm/s range. Wu et al.(11) estimate no difference of mean pore water velocity in the Ap layer of no-till versus moldboard plow systems, but there was a marked reduction of mean pore water velocity in the packed layer of the moldboard treatment (see the K_{sat}=20μm/s in Table 1) when the plow pan (8) was included in the sample. Wu et al. (10) demonstrated a significant relation between mean pore water velocity and macropore conductivity (a combination of K_{sat} and K_{unsat} in Table 1).

Table 1. K_{sat} and K_{unsat} (μm/s) in a Nicollet-Webster silty clay loam layered by tillage.

Method[1]	Ap layer (0 - 25cm)		Packed layer (25 - 40cm)		Source
	Chisel or moldboard	No-till or ridge-till	Chisel or moldboard	No-till or ridge-till	
5-cm cores, FH[2]	18	24	45	25	(8)
Soil structure (12)[3]	23	23	43	23	(8)
5-cm cores, CH	53	53	84	98	(9)
30-cm cores, CH	250	200	20	300	(9)
Tension infiltrometer(-3 kPa)	2	2	2	5	(9)

[1] core diameters are 5 and 30 cm, respective lengths are 6 cm and 25 cm; in Logsdon et al. (8) the depth ranges are 7 to 13 and 32 to 38 cm; in Wu et al. (9) the 5-cm cores have depth range 3 to 9 cm and 25 to 31 cm, and the 30-cm cores have depth range of 0 to 25 cm and 25 to 50 cm; [2]FH is falling head, and CH is constant head; [3] soil structure is an indirect method to estimate K_{sat}.

CONCLUSIONS

Detailed examination of soil layers in the tillage-layered profile indicates a significant macroporosity in the tilled layer and adjacent subsoil layer (packed layer in Figure 1) of both tillage systems, i.e. those which do or do not receive the annual full-width primary tillage. The major difference is an internal catchment formed by traffic and/or tillage tool, which was confirmed by dye tracing. Incorporated crop residues and herbicides within macropores of the Ap layer have a strong exposure to this macroporous flow system. In the no-till or ridge-till systems incorporated herbicides and fertilizer are often band applied/injected near the row; thus agrichemicals in these two systems are exposed to the macropores demonstrated to occur in the Ap layer (Table 1).

Zones of soil compaction were avoided in these studies, but must be considered to obtain a spatially integrated measure of water flow and transport of agrichemicals. When compacted by surface traffic the zone of discontinuity between macropore dominated layers would thicken and begin closer to the surface, and perhaps the macropore component of K_{sat} would be reduced. although the K_{sat} values would reflect more than the matrix K_{sat}.

The Nicollet-Webster is a highly structured soil with a deep mollic epipedon. In soils with a poorly structured subsoil, the typical layered profile may require extensive modification to evaluate bypass flow.

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IMPACT OF LONG-TERM DIFFERENT TILLAGE SYSTEMS ON WATER INFILTRATION AND BROMIDE DISPLACEMENT OF A LOESSIAL AND A SANDY SOIL

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ABSTRACT

On a loessial and a sandy soil, long-term different tillage systems resulted in different pore structures. The higher abundance and activity of earthworms in the direct-drilled plot created more biogenic, continuous macropores than in the ploughed one. The results demonstrate that the bimodal porosity in the direct-drilled plot causes a deeper tracer displacement than in the ploughed one. This preferential solute movement through the no-tillage soil profiles was confirmed by calculated water infiltration. With a simulation modell based on the Richards-equation and measured matrix-suctions, the water fluxes through the soil matrix were computed. From the differences between the real infiltration and the calculated soil matrix infiltration-capacity, the proportion of macropore-flux was estimated and in similar magnitude as calculated from the bromide depth-distributions.

INTRODUCTION

While ploughing increases the volume of large pores by loosening the topsoil, the structure of the soil surface and the continuity of macropores could be destroyed. In contrast, the better subsoil rooting and higher biological activity in no-tillage result to an increased number of continuous biopores, created by earthworms and plant roots. It is often assumed that the risk of groundwater contamination caused by macropore flow is higher by conservation-tillage and no-tillage than by conventional tillage. On the other hand, many measurements demonstrate that long-term missing soil loosening results in a higher bulk density and lower macroporosity in the topsoil than in ploughed soils (2). According to that, a lot of researchers found that the infiltration rate and the saturated hydraulic conductivity were lower in no-tilled than in tilled soils. As yet, there is a lack of field experiments on long-term different tillage systems to assess the risk of groundwater pollution by macropore flow.

The objectives of this research were: 1) to investigate the effect of long-term different tillage system on pore structure and water infiltration; 2) to assess tillage effects on the risk of groundwater contamination by macropore flow with surface applied tracer (bromide).

MATERIALS AND METHODS

Field sites, tillage treatments and soil physical properties

Two locations in central Hesse/Germany with different tillage treatments for more than 10 years were selected for this study. The first is an aggregated loessial Luvic Phaeozem (FAO) with a gleyic subsoil and 11.5 % sand, 67.3 % silt, and 21 % clay in the topsoil. The second site is an unstructured Eutric Cambisol (FAO) with 66.1 % sand, 28.7 % silt and 5.3 % clay in the topsoil. More details about the soils are shown in table 1. On both sites the experiments were carried out on the ploughed (CT) and direct-drilled (NT) plots. For more informations about tillage treatments, crop management, and field sites see (2).

Undisturbed soil cores were taken from the CT and NT plot in spring 1989 on the Luvic Phaeozem and in spring 1990 on the Eutric Cambisol. The soil was sampled when, regarding the previous weather, the water content was near field capacity. The bulk density ρ_b, the particle density ρ_s, the total porosity TP and the water retention curve WRC, using tension plates and standard pressure chambers, were determined. From these data the air-capacity AC (> - 6 kPa) , the available water content AWC (- 6 kPa ... - 1500 kPa) and the readily available water content RAWC (- 6 kPa ... - 100 kPa) were calculated. The saturated hydraulic conductivity K_{sat} was measured by using the constant head method. According to (5), the visible biopores (Ø > 1 mm) in 10 and 40 cm depth of the Luvic Phaeozem were counted and classified on each plot in May and October 1989, and the frequency size-distribution and the total area of biopores were calculated.

Table 1: Characteristic data of the soils used in this study (means over all tillage treatments)

Horizon*)	Depth [cm]	Texture*)	ρ_s [$Mg \cdot m^{-3}$]	ρ_b [$Mg \cdot m^{-3}$]	TP % [v/v]	pH $CaCl_2$	$CaCO_3$ % [w/w]	$C_{org.}$ % [w/w]
			Luvic Phaeozem					
Ap1	0-25	Lu	2.63	1.31	50.2	7.1	0.58	1.59
Ap2	25-35	Lu	2.64	1.45	45.1	7.1	0.58	1.24
AhBt	35-80	Ltu	2.67	1.48	44.6	7.4	0.47	0.69
GoBvt	80-95	Ltu	2.67	1.49	44.2	7.6	1.25	0.46
			Eutric Cambisol					
Ap	0-30	Su3	2.60	1.66	36.2	5.4	-	0.66
Bv	30-40	Su3	2.62	1.74	33.6	5.5	-	0.26
II SwBv1	40-60	Sl4	2.63	1.76	33.1	5.6	-	0.19
II SwBv2	60-80	Sl4	2.67	1.75	34.5	5.6	-	0.06

*) after the German classification system (1)

Displacement of a conservative tracer (bromide) under simulated rainfall

To avoid significant effects by changing water contents on bromide displacement, artificial rain was applied with a swing-jet rainfall-simulator (8.1 m^2 subplot area) and a rainfall intensity of 50 mm h^{-1} to attain field capacity (rain I). After removing the crops carefully, the sprinkling was started on both sites on the ploughed plot until free water appeared on the soil surface. Then the direct-drilled plot was sprinkled as long as the ploughed trial. After 2 days, a KBr-solution (1.3 mm) with a concentration of 30.8 $g \cdot L^{-1}$ bromide was sprayed as uniform as possible on each subplot and after that the plots were again sprinkled (rain II). Again, the simulated rain was stopped when ponding occured on the surface of the ploughed plot. The soil was covered with a plastic sheet to avoid evaporation. After 2 days of water equilibration, the soil was sampled up to 40 cm with 250 cm^3 cores. Soil samples were taken from 40 to 90-100 cm depth with a single gouge auger. The resident bromide concentrations were determined by potentiometric titration. During the experiments, the soil water suction was continuously collected in 5 depths with pressure transducer tensiometers.

RESULTS AND DISCUSSION

Table 2 demonstrates that the recurring soil loosening causes on both sites lower ρ_b and correspondingly higher TP values in the topsoil in CT than in NT. In contrast, the lower ρ_b and higher TP values in NT below the tillage layer indicate a plough pan in the CT trial of the loessial soil. The pore characteristics demonstrate clearly that the higher soil compaction, caused by long-term remaining soil loosening, results in a lower macroporosity, but a higher water storage capacity in NT than in CT. Reversed relations were found below the cultivation depth of 25-30 cm. On the unstructered sandy soil, the differentiation of pore-structure is less pronounced. The higher K_{sat} values in the topsoil in CT, compared to NT, correspond in general with the tillage induced differences of soil macroporosity.

Table 2: Effects of tillage system on porosity of the Luvic Phaeozem and the Eutric Cambisol

Depth [cm]	ρ_b [$Mg \cdot m^{-3}$]		TP [% v/v]		AC [% v/v]		AWC [% v/v]		RAWC [% v/v]		K_{sat} [$cm \cdot d^{-1}$]	
	CT	NT	CT	NT	CT	NT	CT	NT	CT	NT	CT	NT
Luvic Phaeozem												
3- 8	1,20	1,41	54,3	46,5	24,7	6,3	15,2	24,7	5,9	6,1	-	-
11-16	1,27	1,53	51,6	42,0	20,4	3,8	16,7	22,7	4,9	4,7	830	21
19-24	1,25	1,47	52,4	44,1	20,9	6,0	16,5	21,6	4,8	5,8	-	-
27-32	1,40	1,46	46,9	44,4	13,6	10,7	16,7	16,7	4,9	5,9	-	-
35-40	1,49	1,40	43,4	46,8	9,7	14,3	16,9	15,6	5,3	4,9	52	50
Eutric Cambisol												
3- 8	1,57	1,61	39,8	38,3	15,8	9,4	13,2	12,3	7,0	7,6	511	80
11-16	1,69	1,71	35,0	34,5	9,3	8,4	13,0	13,7	8,0	8,2	434	161
19-24	1,63	1,67	37,4	36,0	13,5	13,8	13,1	10,3	6,8	5,8	919	168
27-32	1,73	1,64	33,8	37,3	8,3	15,2	16,5	10,9	8,5	6,9	201	355
35-40	1,74	1,64	33,2	37,7	7,6	16,2	12,5	10,9	8,0	7,1	397	236

From table 3 it appears that the lower macroporostiy in the topsoil of NT is attended by a significantly higher number of visible biopores, especially in the area between the topsoil and the subsoil. This considerably higher number of biopores is affected by a higher earthworm abundance in NT than in CT (6). However, these biopores represent only a small proportion less than 2.5 % of the total mapped area. Colouring tracer tests from (2) prove that only a certain proportion of biopores is continuously opened up to the soil surface and thus, is going to be hydraulically effective during heavy rainfalls.

Table 3: Visible biopores (Ø > 1 mm) on the CT and NT plot of the Luvic Phaeozem

Depth [cm]	CT N	CT mm^2	CT %	NT N	NT mm^2	NT %
10	50^a	267	0,22	58^a	1111	0,89
40	48^a	288	0,23	135^b	1966	1,58

N = number of biopores, mm^2 = total area of biopores, % = biopore area in per cent of the mapped area of 0.125 m^2; Values with different superscripts are significantly different ($\alpha < 0,05$ Tuckey-Test)

In order to estimate the unsaturated hydraulic conductivity K_u, the Van-Genuchten equation (9) was fitted to the measured θ-(ψ)-values, and the relative hydraulic conductivity K_r was predicted according to Mualem's pore model (8). The normally used Van-Genuchten equation assumes that soil porosity has a unimodal, normal-shaped frequency density distribution. As it is proved by (4), this functional description cannot properly represent pore structures with secondary pore systems, created by aggregation processes or macropores. For a proper description of such "multiporosity soils", Durner (4) developed a multimodal water retention curve (WRC), which is given by a linear superposition of subcurves of the Van-Genuchten type, combined with numerical K_r-predictions according to Mualem's theory.

As an example, it is demonstrated in Figure 1 that for the aggregated loessial soil, the coincidence between the unimodal WRC and the measured values is poor, whereas the bimodal

WRC properly represents the measured data. In contrast, the pore system of the unstructured sandy soil could be adequately represented by the unimodal WRC. The computations proves that the pore-system in the topsoil of the aggregated loess soil is bimodal, especially in NT, whereas the unstructured sand soil has a unimodal pore-system. For more details see (2).

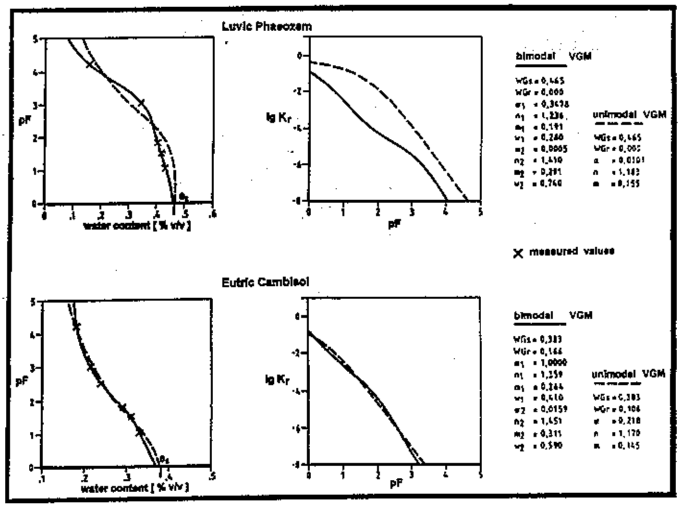

Figure 1: Measured retention data and fitted unimodal and bimodal water retention curve and predicted K_r-functions from the direct-drilled plot (3-8 cm depth) of the Luvic Phaeozem and Eutric Cambisol (VGM = Van-Genuchten-Mualem model)

Based on the bimodal fitted WRC and the predicted K_r-funtions, the hydraulic properties of the soil matrix were caclulated. The K_r-functions were transformed to absolut K_u-values by using the measured K_{sat}-values. Using the continuously measured matrix suctions (data not shown), the water infiltration in the soil matrix was simulated by solving the Richards-equation with the Newton-Raphson-algorithm. The boundary conditions were choosen according to the real infiltration experiments. More details about the boundary conditions and the simulation model are reported by (2).

The simulation results demonstrate that on both sites the infiltration-capacity of the soil matrix in the direct-drilled treatment is not sufficient to infiltrate the applied rain. The main reason for this insufficient infiltration-capacity is the lower macroporosity and therefore lower saturated hydraulic conductivity of the soil matrix in NT compared to CT. In contrast, the infiltration-capacity of the soil matrix in CT is sufficient to infiltrate the applied rain completely. Because the fields are plane on both sites, no runoff occured and all the applied rain was actually infiltrated in the soil profile in CT as well as in NT. The calculated matrix-flow in NT was about 20 % of the infiltrated rain in the finer textured loessial soil and about 60 % in the coarser sandy soil. In CT the calculated matrix-flow was 100 % of the infiltrated rain on both sites. Thus, the difference between the calculated matrix-flow and the really infiltrated rain in NT is attributed to macropore flow in the frequently continuous biopores.

The higher proportion of macropore-flow in NT is supported by the results of the bromide depth-distributions. Figure 2 shows that in NT more bromide was displaced in greater depths than in CT on both sites. With a simple approach according to (7), parameters characterizing the tracer movement are calculated. As an example, the results in table 5 demonstrate that, with comparable mean water contents Θ, the Darcian-water velocity v_D and the pore-water velocity v_0 were higher in CT than in NT. In contrast, the tracer-migration velocity v_a was higher in NT than in CT. Furthermore, the bromide-migration velocity v_a was higher than the pore-water velocity v_0 in CT and NT, so that a preferential bromide transport must be considered. The relationship between v_0 and v_a characterizes the effective porosity, which was smaller 1. This clearly indicates a certain amount of fast water flow (macropore flow) ahead of the main infiltration front in CT as well as in NT, but which was considerably higher in NT than in CT.

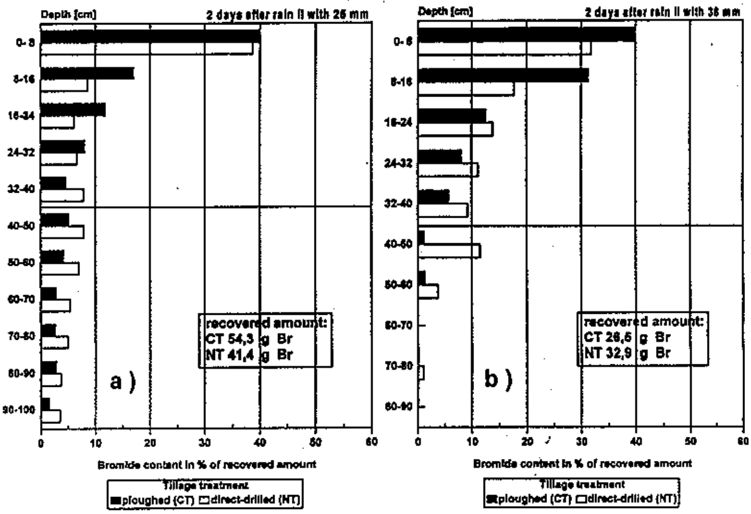

Figure 2: Mean bromide content in % of total recovered amount in the soil profile 2 days after simulated heavy rainfall (rain II) of the Luvic Paeozem (a) and the Eutric Cambisol (b)

Table 5: Parameters of bromide displacement caused by simulated high-intensity rainfall ($50\ mm{\cdot}h^{-1}$) in relation to tillage treatment of the Luvic Phaeozem, rain II

Parameter		CT	NT
Θ	$[m^3{\cdot}m^{-3}]$	0,377	0,348
q	[cm]	2,58	1,89
v_D	$[cm{\cdot}h^{-1}]$	0,054	0,039
v_0	$[cm{\cdot}h^{-1}]$	0,143	0,111
v_a	$[cm{\cdot}h^{-1}]$	0,194	0,324
v_0/v_a		0,737	0,343

$v_D = q\,t^{-1}$; q = water fluxes through the soil profile, t = time; $v_0 = v_D\,\Theta^{-1}$; $v_a = z_a\,t^{-1}$; z_a = depth of the mass center

CONCLUSIONS

To what extent a greater amount of macropore flow in NT causes a higher risk of groundwater contamination depends, above all, on the initial water content, the rain intensity and the pollutant position (fig. 3). Macropore flow does only appear if the rain intensity is higher than the infiltration capacity of the soil matrix (3). Colouring tracer tests under artificial heavy rainfalls from (2) verify that, if the initial water content is clearly below field capacity, only the macropores opened up to the soil surface could transport water and dissolved solutes rapidly in greater depths. This bypass-flow results in the fact that a great part of rainwater passes the soil matrix and thus, it represents a considerable transfer risk for substances which are soluble in rainwater or situated in easily soluble form on the soil surface. If, however, the pollutant position is located within the soil matrix, the bypass-flow reduces the advance depth of the main infiltration front so that the danger of elution of pollutants is diminished. On the other side, in the event of heavy rains and initial water contents near field capacity, the presented infiltration experiments and bromide depth-distributions prove that the pore system of the topsoil is saturated rapidly so that the total coarse- and macropore-system becomes hydraulically effective. In this case of preferential flow, a higher number of continous biopores in NT also means a higher risk of groundwater contamination, both for substances in the rain water or on the soil surface as well as for those in the soil matrix. In the scheme in figure 3, chemical interactions and equilibrium kinetics between the liquid and solid phase were disregarded. These topics and a final judgement of the risk of groundwater contamination caused by macropore flow requires further research.

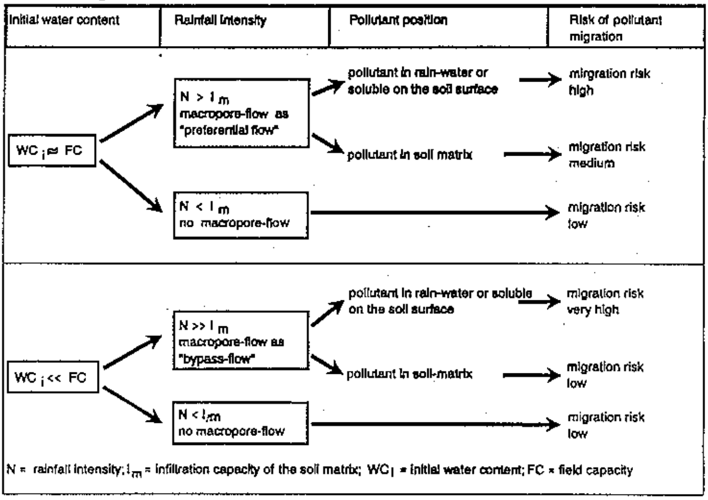

Figure 3: Assessment of the risk of groundwater contamination caused by high-intensity rainfalls on soils with continuous macropores

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SURFACE RUNOFF, EROSION AND LOSS OF PHOSPHORUS RELATIVE TO SOIL PHYSICAL FACTORS AS INFLUENCED BY TILLAGE AND CROPPING SYSTEMS

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ABSTRACT

Surface runoff, erosion, losses of soil and phosphorus (P), and related soil physical properties were studied in differently cultivated plots on 10 % sloping areas at Foulum (loamy sand) and Ødum (sandy loam) in Denmark, 1989-92. Cultivations were (summer / winter): Permanent ryegrass; Spring barley / ryegrass; Spring barley / mouldboard ploughed; Winter wheat drilled up and down slope; Winter wheat drilled across slope; Fallow.

Seedbed preparation for winter wheat and harrowing of the fallow plots lowered the capacity of the surface soil for both water assimilation and storage of ponding water, favouring surface runoff and erosion compared to ploughed soil. Soil structural stability in treatments not covered by grass during winters decreased over the years.

Surface runoff, erosion and P losses varied tremendously with season, year, cultivation and site. Far the greatest rates were recorded from October to March. The surface runoff, soil and P losses varied from 0.6 to 167 mm/y, 0.004 to 26 t soil/ha/y and 0.01 to 33 kg total P/ha/y, respectively. The magnitudes generally followed the order: fallow > wheat-up-down > wheat-across > > barley-ploughed > barley-catch crop > permanent ryegrass.

INTRODUCTION

Water erosion seems to be an increasing problem in northern Europe (1). Soils are degraded and nutrients are transported to the aquatic environments. Little is known about the extent of these processes and their variation with land form, land use, soil type and climate in Denmark (2). The erosivity of the rain in Denmark is rather low (USLE EI_{30}: 23-63 kJ m^{-2} mm h^{-1} 1985-91). However, low-intensity rain may cause ponding, surface runoff and erosion depending on (i) the ability of the soil to assimilate rain, (ii) the capacity of the soil surface roughness to store ponding water, and (iii) the soil structural stability, i.e. ability of the soil to resist shear stresses from flowing water. Water erosion mainly take place during the autumn winter period in temperate regions, so the autumn soil management is a key factor for the soil physical properties and the course and extent the erosion (3, 4). As much as 55 % of the total, Danish land area is arable and about one third of this is covered by cereals or rape during winters.

The aim of this work was to study the effects of different tillage and cropping systems on surface runoff, soil erosion and losses of phosphorus (P) under Danish conditions and furthermore to try to relate these phenomena to soil physical properties.

MATERIALS AND METHODS

Eight plots of 22.1 x 3.0 m were laid out in the autumn 1989 at Foulum and Ødum in Jutland, Denmark on land sloping ca. 10 %. For three years surface runoff, erosion, loss of P, and related soil physics were studied. The Foulum soil is a loamy sand containing 8.8, 9.9, 35.6, 43.6 and 2.1 % of clay, silt, fine sand, coarse sand and organic matter, respectively. The Ødum soil, a sandy loam is containing 10.6, 12.5, 43.6, 31.4 and 1.9 %, respectively. Both soils are rich in available P (> 50 mg/kg of HCO_3^--extractable Olsen-P). The following six treatments were applied:

GRS Permanent ryegrass; cut four times per year.
CCR Spring barley followed by a ryegrass catch crop during winter; ploughed in spring.
PLG Spring barley; ploughed in autumn.
WUD Winter wheat drilled up and down the slope; ploughed in autumn.
WAC Winter wheat drilled across the slope; ploughed in autumn.
FLW Fallow; ploughed in spring and harrowed from time to time to remove weeds.

Only WUD and FLW treatments were repeated. All plots were framed by 10 cm boards and separated by paths of 0.5 m. Troughs at the lower end led the runoff and sediments to 1300 l tanks. They were emptied from time to time and the amounts of water and sediments determined. Samples of surface soil, suspensions, filtrates (0.45 μm) and sediments were analyzed for total P and various P fractions. Precipitation was recorded every minute.

Water infiltration capacity was measured with the double ring method at field capacity. Undisturbed 100 cm^3 cores were sampled from each of the layers: 0-5, 10-15 and 25-30 cm and saturated hydraulic conductivity determined after Klute & Dirksen (5). Aggregate strength was determined according to Hartge (6) in the 0-5 cm layer.

Roughness profiles of the soil surface were obtained with an automated surface profile meter along up-down-slope lines of 132 cm (3 cm between readings, 34 lines per plot, 6 cm between lines) from which RE-indexes (Residual Error) and DSC-indexes (Depression Storage Capacity) were calculated. The RE-index was simply calculated as the square root of the mean square error of linear regressions on the up-down-slope recordings of height. The DSC-index was calculated from up-down-slope line profiles obtained by connecting the height

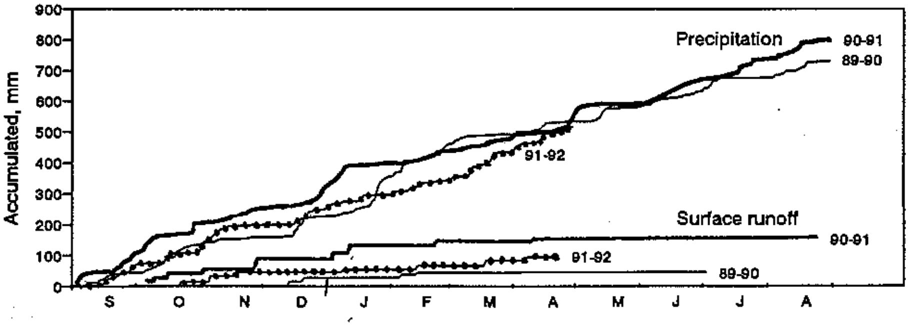

Fig. 1. Cumulative precipitation and surface runoff from WUD plots at Foulum.

recordings of each up-down-slope line with straight lines. A hypothetical "water storage area" (cm^2cm^{-1}) was then computed for each profile irrespective of the shape of the neighbouring profiles by calculating the area between each profile and horizontal lines drawn at imaginary water levels before runoff. Finally a mean DSC-index of all profiles were calculated per plot. The final unit is cm or cm^3cm^{-2} if the profile calculations are thought to represent all the surface. All destructive soil physical measurements were made on similarly treated plots located just above the runoff plots.

RESULTS AND DISCUSSION

All three winters were mild with only one period of rapid snow melting in February 1991. Large rainfalls occurred during winter 89/90, autumn 90 and spring 92 (Fig. 1). Far the most of the surface runoff took place from October to March (Fig. 1). The very wet 90 autumn resulted in surface runoff from the start (Fig. 1). Widespread erosion took place in Denmark that autumn in areas with newly prepared seedbeds for winter cereals.

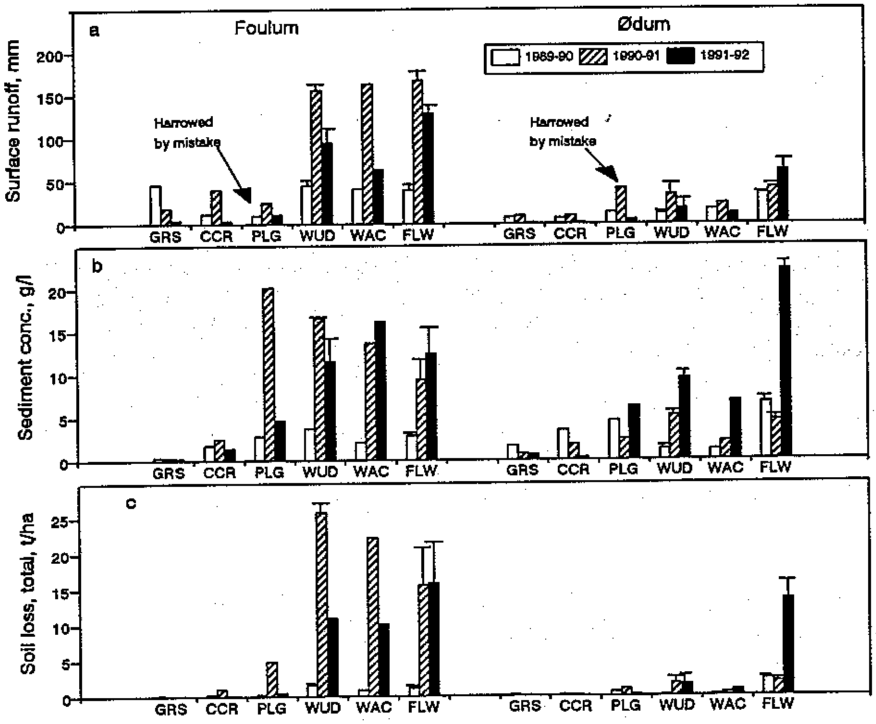

Fig. 2. (a) surface runoff, (b) sediment concentration (total sediment loss divided by total surface runoff) and (c) total soil loss from different treatments. Error bars indicate maximum values of two replicates.

Foulum generally had much more surface runoff and erosion than Ødum (Fig. 2), probably because the water assimilation capacity of the Foulum soil generally was less than that of the Ødum soil (Table 1). A quarter to a third of the surface runoff in Foulum during 89/90 and 90/91 occurred when the soil was frozen. Grass covered (GRS, CCR) and ploughed (PLG) plots had much less surface runoff and erosion than wheat covered (WUD, WAC) and fallow (FLW) plots (Fig. 2a), most likely due to different capacities for water assimilation (Table 1) and for storage of ponding surface water (Table 2). The physically based DSC-index is probably slightly overestimating the real storage capacity of ponding surface water. However, it is believed to be a better estimation of the true storage capacity than the statistically based RE-index (Table 2).

Table 1. Water assimilation measures determined in the field (Infiltration capacity, double ring technique, autumn and spring, 2 replicates per plot) and in the laboratory (Steady state saturated hydraulic conductivity in 100 cm^3 cores collected in spring from 0-5 and 10-15 cm depths, 10 replicates per layer and plot).

	Foulum					Ødum				
	PLG	WUD	WAC	FLW	LSQ[1]	PLG	WUD	WAC	FLW	LSQ[1]
Infiltration capacity, mm/h										
	363	16	17	4	4.0	151	120	69	18	3.2
Saturated hydraulic conductivity, mm/h										
	157	63	34	84	n.s.	209	212	188	54	n.s.

[1] LSQ = Least significant quotient.

Sediment concentrations generally increased with increasing surface runoff (Fig. 2b). The large sediment concentration of PLG at Foulum in 90/91 dates from a heavy rainfall on a newly prepared seedbed in spring. The resulting losses of soil (Fig. 2c) were quite large from the wheat covered and fallow plots in Foulum. The difference between treatments confirm the observations of Colborne & Staines (4) that winter-cereal fields are more prone to water erosion than ploughed ones. Relative to a ploughed soil surface, seedbed preparation for winter cereals promotes surface runoff and erosion by levelling the surface, compacting the soil and breaking down soil structure. The sparse vegetation in winter-cereal fields during winter time yields little shelter against the soil-slaking effect of raindrops, little resistance to surface runoff and has little soil binding capacity.

Table 2. Measures of soil surface roughness based on 34 up-down-slope lines per plot (see text). SD indicates average inter-line variation within each plot.

		Foulum				Ødum			
		PLG	WUD	WAC	SD	PLG	WUD	WAC	SD
RE-index, cm	1990	1.38	0.63	0.93	0.18	0.60[1]	0.55	1.23	0.09
	1991	1.64	0.57	1.35	0.36	1.33	0.81	1.10	0.22
DSC-index, cm	1991	0.98	0.15	0.75	0.32	0.87	0.48	0.83	0.27

[1] Harrowed by mistake

Average results of surface runoff, losses of soil and losses of dissolved and total P over the three years are shown in table 3. The rates generally followed the order FLW > WUD > WAC >> PLG > CCR > GRS. The level of dissolved-P losses was similar to generally recorded, vertical leaching losses of dissolved P in agricultural areas. The level of total P losses, however, was 10 to 100 times greater. The variation pattern of total P losses was similar to that of total soil losses (Fig. 2c) as the dissolved P, except for the GRS treatment, contributed so little to the total P loss (Table 3).

Table 3. Surface runoff and losses of soil and P from variously treated plots in Foulum and Ødum. Average per year 1989-90 to 1991-92.

	Foulum						Ødum					
	GRS	CCR	PLG	WUD	WAC	FLW	GRS	CCR	PLG	WUD	WAC	FLW
Surface runoff, mm												
	11.0[1]	18.4	17.4[2]	98.4	89.1	111.6	4.7[1]	5.3	8.9[3]	20.9	16.9	46.2
Soil loss, t/ha												
	0.031[1]	0.415	2.69[2]	12.79	11.08	10.87	0.033[1]	0.126	0.447[3]	1.17	0.489	5.93
Dissolved P loss, kg/ha												
	0.135[1]	0.152	0.110[2]	0.317	0.277	0.385	0.062[1]	0.053	0.047[3]	0.115	0.118	0.179
Total P loss, kg/ha												
	0.183[1]	1.29	3.20[2]	17.3	15.2	20.0	0.096[1]	0.175	0.498[3]	1.86	0.807	6.73

[1] Excluding year of establishment. [2] Excluding first year erroneously harrowed. [3] Excluding second year erroneously harrowed.

A decrease in aggregate stability during the three-year period took place both in Foulum and Ødum in PLG, WUD, WAC and FLW, i.e. in the treatments not covered with grass during winters (Fig. 3). This probably has affected the long-term development of the erosion processes. The intra-aggregate stability data shown here, however, are not expressing the strength of the bulk soil, which probably is of most interest relative to erosion resistance. Furthermore, they are not suitable for comparing the two soil types.

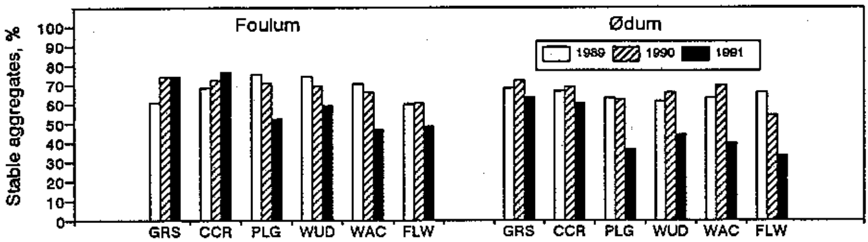

Fig. 3. Aggregate stability of differently treated soil: Part of aggregates, originally of 2-8 mm, which maintained a diameter > 1 mm after wet sieving.

Only one other project concerning erosion from plots has been carried out previously in Denmark (2), but very little runoff and soil losses were recorded from the five studied soils. The winters were mild and the soils probably were not susceptible to water erosion. Two of them were coarse sands, sloping only 4%, one was a loam sloping only 2%. and one was a sandy loam sloping 12%. But the latter had a ploughed winter surface all years, which, according to our results, is not prone to water erosion during mild winters in Denmark.

The erosion studies at Foulum and Ødum are continuing for another three-year period which started 1993. They have now better instrumentation for continuous recording of surface runoff and water content in the soil and for sampling. A detailed description of the present layout and instrumentation is given in the ISTRO Excursion Guide to the visit of Research Centre Foulum on July 27, 1994.

CONCLUSION

Under Danish conditions with relatively mild winters, surface runoff, erosion and loss of P during the autumn-winter period is much affected by year, soil type and cropping system. Land with winter cereals secm to be much more susceptible to surface runoff, erosion and P losses than ploughed land, pasture or fields with catch crops. Relative to a ploughed soil seedbed preparation decrease the capacity of the surface soil for water assimilation and storage of ponding water favouring surface runoff and erosion.

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INTERRILL SOIL EROSION AND HERBICIDE MOVEMENT FOR NO-TILL AND CONVENTIONAL TILLAGE SYSTEMS IN CENTRAL USA

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ABSTRACT

No-till cropping systems are effective in reducing soil erosion. No-till production systems, however, often require increased herbicide inputs which may result in increased herbicide migration to non-target sites. The objectives of this research were to determine the primary cause of reduced erosion in no-till systems, whether primarily soil structure or residue cover effects, and to measure the effects of formulation on atrazine migration in conventional and no-till systems. Surface runoff, sediment loss, and herbicide movement were measured in central Illinois, USA using simulated rainfall on interrill erosion plots with and without residue cover on no-till and conventional tillage plots treated with commercial liquid or experimental starch encapsulated formulations of atrazine. Removing the crop residue resulted in increased soil loss, decreased water infiltration rates, and increased herbicide migration. Experimental starch encapsulated formulation reduced atrazine loss compared to the commercial liquid formulation regardless of tillage system or the presence or absence of residue. The highest herbicide loss occurred from plots that were conventionally tilled, had residue removed and received commercial liquid formulations of atrazine. The least herbicide loss was recorded from no-till plots with residue in place and starch encapsulated formulations applied. Tillage with no residue resulted in a much greater decrease in infiltration rate and greater increase in soil loss than tillage without removing residue.

INTRODUCTION

Conservation tillage, which minimizes soil disturbance and maintains a cover of residue on the soil surface, has been widely accepted in the Midwest USA due to its control of soil erosion by water. Conservation tillage, however, has increased the use of chemicals while reducing tillage practices. Lack of soil disturbance has greatly increased infiltration rates in the deep loessial regions of the Midwest and reduced runoff. Because of increased water penetration into the soil profile, concerns have been raised regarding the increased movement of pesticides into the soil. With less runoff, the herbicide loss via surface water runoff is less. The purpose of this study was to evaluate the transport of sediment and pesticides from interrill areas.

MATERIALS AND METHODS

Simulated rainfall experiments were conducted at three sites near Lexington, Illinois. Soil at sites 1 and 3 was a moderately well-drained, Saybrook silt loam (fine-silty, mixed, mesic Typic Argiudoll). Texture was 8% sand, 79% silt, and 13% clay. Soil at site 2 was a moderately well-drained, Corwin silt loam (fine-loamy, mixed, mesic Typic Argiudoll). Texture was 13% sand 71% silt, and 16% clay. Organic carbon for both soils was about 2.5%.

Soil tillage treatments

Site 1 was a corn-soybean rotation under conventional tillage. Tillage operations were chisel plow with twisted shank, tandem disk, and field cultivator in the spring. Treatments imposed on 1 m wide and 2 m long plots were:

1) freshly tilled (T-R), and

2) freshly tilled, with residue removed before tillage (T-NR). Treatments were replicated six times.

Sites 2 and 3 were located in adjacent fields in a corn-soybean rotation under no-till for 15+ years. Previous crop at site 2 was corn; at site 3, soybeans. Treatments were:

1) no-till (NT-R),
2) no-till + crop residue removed (NT-NR),
3) till + crop residue replaced on surface (T-R), and
4) till + crop residue removed prior to tillage (T-NR).

For treatments 3 and 4, crop residue was removed and plots were tilled by hand hoeing. Residue was replaced on treatment 3 plots. Percent residue cover was measured on each plot.

Soil erosion sampling

Runoff, erosion, and infiltration were measured on 1 m wide and 2 m long plots using a programmable rainfall simulator [1]. The rainfall simulator was located 3.0 m above each plot and used oscillating Veejet 80150 nozzles. Runoff and soil loss were measured at 5 min intervals throughout each run. Infiltration rate was calculated as the difference between rainfall and runoff.

Herbicide measurements

Atrazine was applied on each residue cover/tillage treatment at sites 1 and 2 as a spray for the commercial liquid (CF) and as experimental starcb encapsulated (SE) granules at 2.8 kg/ha approximately 1 hour before rainfall began. During each rainfall simulator mn, mnoff samples were collected at 5 min intervals. Samples for herbicide analysis were spiked with an internal standard and stored under refrigeration until processed. Tbe water samples were filtered, sediment content determined, and the atrazine extracted using solid phase extraction techniques. Herbicide residues were quantified by gas chromatography.

RESULTS AND DISCUSSION

Residue cover following rainfall simulation was estimated to be 12% on the conventional tillage treatment (site 1), 60% on the no-till with soybean residue, and 95% on the no-till with corn residue. Residue cover on plots with residue removed was near 0%.

Removing the 12% residue cover on the conventional tillage plots at site 1 decreased the final infiltration rate from 62.1 to 39.2 mm/h and increased the soil loss from 0.13 to 0.52 kg/m^2/h (Table 1). On the no-till sites 2 and 3, soil loss was low and infiltration rates were high if residue cover was left on the surface, even if the plots were tilled. At a rainfall intensity of 70 mm/h, removing residue on the no-till plots resulted in a smaller increase in soil loss and smaller decrease in infiltration rate than removing residue on the tilled condition. The tillage effect under no residue had a greater effect on changing infiltration and erosion rates than the tillage effect with residue cover.

Table 1 Final infiltration (FIR) and soil loss rates after 90 min of simulated rainfall (70 mm/h) in June 1992.

Tillage/ residue cover treatment	Site 1 Conv. till FIR (mm/h)	Site 1 Soil loss (kg/m^2/h)	Site 2 No-till/corn FIR (mm/h)	Site 2 Soil loss (kg/m^2/h)	Site 3 No-till/soybean FIR (mm/h)	Site 3 Soil loss (kg/m^2/h)
T-NR	39.2	0.52	35.2	0.59	32.4	0.76
T-R	62.1	0.13	66.1	0.04	-	-
NT-NR	-	-	52.9	0.13	41.2	0.16
NT-R	-	-	70.0+	0.01	70,0+	0.01
LSD(0.05)	4.9	0.22	8.0	0.18	4.7	0.12

Freshly tilled with residue removed (T-NR), freshly tilled with residue (T-R), no-till with residue removed (NT-NR), and no-till with residue (NT-R).

Table 2 shows the added effect of soil drying for three days on tilled and no-till conditions with residue cover removed. Soil loss on a dried, crusted soil surface with residue removed was considerably less for the no-till compared to tilled treatment due to greater soil resistance of the no-till surface, even though runoff was greater for the no-till treatment. At a rainfall intensity of 100 mm/h, soil loss rates for tilled and no-till plots with residue are extremely low due to low runoff rates. Even at equal runoff rates, surface residue protects the soil surface from raindrop impact forces and limits sediment transport across the surface, resulting in low soil loss.

Table 2 Final infiltration and soil loss rates for site 3 (no-till, following corn harvest) in October 1992 (rainfall intensity = 100 mm/h).

Tillage/Residue cover treatment	Infiltration (mm/h)	Runoff (mm/h)	Soil loss ($kg/m^2/h$)
With residue cover			
No-till (NT-R)	87.7	12.3	0.01
Till (T-R)	89.3	10.7	0.02
Residue removed			
No-till (NT-NR)	26.2	73.8	0.94
No-till, dried surface	15.0	85.0	1.96
Till (T-NR)	32.2	67.8	2.45
Till, dried surface	21.4	78.6	3.77

Statistically significant formulation, crop residue, and tillage effects on atrazine amounts in both runoff water and soil sediment were found (Table 3). When data were averaged over tillage and residue cover, the CF lost 1.06% of applied atrazine in the runoff water compared with 0.21% loss for the SE formulations. This is a reduction of nearly 80% by the SE. Runoff losses from CF atrazine were slightly less than losses from the SE on conventional tillage. On the no-till plots with residue removed, the CF atrazine loss in runoff water was more than 20 fold greater than from the SE formulations. On the no-till plots with residue in place, no herbicide loss via surface movement occurred since infiltration was essentially 100% of rainfall.

In conventional tillage with residue removed plots, transport of herbicides in the sediment was considerably greater for the SE formulation than for the CL (Table 3). With surface residue in place, herbicide loss in the sediment was less than 0.03% for both tillages and formulations.

Table 3 Percent of applied herbicide detected in runoff water and soil sediment.

Tillage/ residue cover treatment	Atrazine Source: Runoff Water		Soil Sediment	
	Formulation: SE	Liquid	SE	Liquid
NT-NR	0.109	2.809	0.255	0.039
NT-R	trace	trace	0.011	0.034
T-NR	0.484	0.355	0.986	0.076
T-R	0.030	0.019	0.034	0.009

CONCLUSIONS

1. Removing surface residue from a no-till plot decreased infiltration rate from 88 to 26 mm/h, at a rainfall intensity of 100 mm/h, and increased soil loss from 0.01 to 0.94 $kg/m^2/h$. Soil loss following removal of surface residue and disturbance by tillage of a no-till plot by tillage was 2.45 $kg/m^2/h$.

2. Tillage under no residue resulted in a much greater decrease in infiltration rate and increase decrease in soil loss than tillage without removing residue.

3. Experimental starch encapsulated formulation reduced atrazine loss compared to the commercial liquid formulation regardless of tillage system or the presence or absence of residue.

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EFFECT OF TILLAGE METHODS ON SOME CHEMICAL PROPERTIES OF ERODED LOESS SOIL

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ABSTRACT

The field experiment was established according to randomized blocks method in 3 replications in the years 1987-1990. The effect of four tillage methods on the content of P_2O_5, K_2O, Mg and humus in two soil layers: 0-0.25 m and 0.25-0.50 m was evaluated. The studies were conducted on severely eroded loessial soil located on southern slope of 15 % inclination. Tillage methods: T1 - conventional (control), T2 - ploughing replaced with cultivating, T3 - ploughing replaced with skimming, and T4 - post-harvest tillage, Gramoxone 5 l/ha with shallower ploughing to 8-10 cm. The above tillage methods were applied for plants cultivated in crop rotation of the following sequence: potato-spring barley-winter rape-winter wheat. The content of elements was examined every year after harvesting a given crop. No erosion damages were recorded on the experimental field during the study. After four-year rotation, the tillage methods did not vary significantly the content of elements studied in both soil layers. There was only trend towards decreasing the content of P_2O_5, K_2O and Mg, most clearly visible after applying the T2 tillage method. Within the entire soil profile 0-0.50 m, irrespective of the layer analysed, the decrease in the content of elements was statistically significant under the conditions of the T2 tillage. The tillage methods did not vary significantly the level of humus content. A half meter thick layer of a strongly eroded loessial soil was protected best, against leaching, by conventional tillage, T1. The effects of a shallow plough tillage, T3, and rototiller, T4, were comparable.

INTRODUCTION

Agricultural utilization of slopes covered with loess, common in undulating terrains in Poland, favours soil degradation. Mechanical soil tillage plays a particular role in this process. It can transfer soil mass down the slope and accelerate erosion and nutrient leaching, causing certain implications in the environment (1,2,3).

The aim of the work was to present the effects of four methods of soil tillage, applied for crops in a four-field rotation, on the content of P_2O, K_2O, Mg and humus in 0-0.25 and 0.25-0.50 m layers of severely eroded loessial soil.

MATERIALS AND METHODS

The field experiments were conducted at the Agricultural Experimental Station at Czesławice (Lublin Upland), on severely denuded loess soil on a southern slope of 15 % inclination with the random blocks design in 3 replications in the years 1987-1990. Soil properties are given in Table 1.

Table 1. Some properties of a severely eroded loess soil of a southern slope of 15 % inclination

Property	Genetic horizon and depth		
	Ap	Ap/C	C
	0-0.3 m	0.3-0.5 m	0.5 m
Sand - 1-0.1 mm (%)	8	7	6
Silt - 0.1-0.02 mm (%)	60	62	64
Clay - <0.02 mm (%)	32	31	30
Soil density (G cm^{-3})	1.54	1.48	1.42
Total porosity (%)	40.1	42.2	45.6
pH (1 n KCL)	6.4	6.4	6.8
Humus (%)	1.23	0.98	0.24
P_2O_5 (mg/100 g)	36.0	34.0	12.4
K_2O (mg/100 g)	28.7	38.3	8.0
Mg (mg/100 g)	12.6	13.2	9.4

Tillage treatments

The following tillage treatments were studied: T1 - conventional tillage, comprising shallow, medium, and deep ploughing according to requirements of a given crop in the rotation (control), T2 - ploughing replaced with cultivating (15 cm deep), T3 - ploughing replaced with skimming (8-10 cm deep), T4 - post-harvest tillage: Gramoxone 5 l/ha with sowing ploughing for winter crops shallowed to 8-10 cm deep.

In the treatments T2, T3, and T4 only farmyard manure was covered by 20 cm deep ploughing. All the cultivation measures were performed across the slope. The described tillage methods were applied for each rotation crop in the following order: potato - spring barley - winter rape - winter wheat. Mineral fertilization NPK was added respectively: 310, 230, and 240 kg/ha and that of FYM 30 t/ha for potatoes.

Soil sampling and analyses

The content of macroelements in soil was analysed every year after harvest of the crop plant. Four soil samples were taken from each replication. Samples from three replications were put together, thoroughly mixed and ground, and than sieved through a sieve of 1.0 mm mesh. The content of P_2O_5 and K_2O was evaluated with Egner-Riehm method, Mg with atomic absorption, and humus content with Tiurin method modified by Simakov.

Weather conditions and erosion damages

Within the study area the mean annual precipitation is 536 mm, and that of temperature 7.2 ^{o}C. In the years of the study period precipitations were below average. No storm rainfalls were recorded and neither intensive snow melting occurred because of mild and low snowing winters. There were not any erosion damages registered in the experimental field. In the neighbourhood area the average soil runoff was minimal, below 0.0004 mm (4).

RESULTS AND DISCUSSION

The studies did not prove any significant effect of the applied tillage methods (T1, T2, T3, and T4) on the content of P_2O_5, K_2O, Mg and humus in respective soil layers (i.e., 0-0.25 m and 0.25-0.50 m). This was probably due to scarce precipitation and lack of erosion damages in the experimental field during four years of the study. Other authors (1,3,5) stated that translocation of nutrients outside the cultivated slope occurs due to erosion processes. There was, however, a slight tendency of decreasing the content of macroelements in both soil layers in plots with simplified soil tillage (T2, T3, and T4) in comparison with the conventional tillage (T1), (Table 2). The highest loss was recorded in plots with cultivating (T2), while the lowest occurred on plots with Gramoxone and shallowed pre-sowing ploughing (T4).

Table 2. Changes in the content of macroelements under the influence of soil tillage methods in arable (0-0.25 m) and subarable (0.25-0.50 m) layers of a severely eroded loess soil. Average of four years (1987-1990).

Macro-component	Soil tillage method			
	T1	T2	T3	T4
	content	change in %		
	0 - 0.25 m layer			
P_2O_5	32.2 mg/100 g	-10.0	-5.6	-3.1
K_2O	29.3 mg/100 g	-7.2	-1.1	-2.1
Mg	10.7 mg/100 g	-3.8	-1.9	-1.9
Humus	1.1 %	-8.5	-6.8	0.0
	0.25 - 0.50 m layer			
P_2O_5	21.8 mg/100 g	-11.0	-6.0	-2.8
K_2O	17.8 mg/100 g	-11.2	-4.0	-1.7
Mg	9.9 mg/100 g	-5.1	-1.0	0.0
Humus	0.64 %	-12.5	0.0	-3.1

In the entire profile 0-0.5 m, irrespective of the soil layer tested, the losses of P_2O_5, K_2O, and Mg were statistically proved in the conditions of the T2 tillage. On the other hand, the changes in humus content, although similar to changes in other components, have not been proved by the test applied (Table 3). Physical properties of a severely eroded loess soil (relatively high contribution of meso- and macropores and low content of colloidal clay) make them permeable (2,6).

This enables nutrients leaching down the soil profile (1). In the conditions of the study, the content of macroelements in the soil was protected best by the T1 tillage, i.e. the system which comprises full set of ploughing turning over the soil and recovering the leached nutrients. The significance of ploughing on permeable soils is beyond argument. Shallow ploughing of the systems T3 and T4 acted much the same as T1, whereas deeper loosening without turning over the soil by T2 caused the highest losses of nutrients. The result was significant decrease in the yield of some crops of the rotation (7), similarly as in other studies (8).

Table 3. Content of some macroelements in 0-0.5 m layer of a severely eroded loess soil. Average of four years (1987-1990). Not significant: n.s.

Macrocomponent	Soil tillage method				LSD acc. Tukey
	T1	T2	T3	T4	
P_2O_5 (mg/100 g)	27.0	24.1	25.7	26.2	1.4
K_2O (mg/100 g)	23.5	21.5	23.0	23.1	1.9
Mg (mg/100 g)	10.3	9.8	10.2	10.2	0.4
Humus (%)	0.91	0.81	0.90	0.90	n.s.

CONCLUSION

In the years with minimal erosion in a severely denuded loess soil on the slope of 15 % inclination there was a migration of plant nutrients down the soil profile. The conventional tillage method (T1) protected the soil best against leaching the nutrients from the layer 0-0.5 m deep. A shallow plough tillage (T4) and rototiller acted similarly, on the contrary to cultivator tillage (T2). This problem needs further studies. They are continued.

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SOIL TILLAGE AND EROSION IN SMALL CATCHMENTS.

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ABSTRACT

Runoff , soil erosion and nutrient losses have been measured in eight small catchments since 1986. The catchment areas, 0.3 - 3.2 ha were mainly clay loam and silty clay loam situated on marine sediments in south eastern Norway. Monitoring stations in each catchment were established for runoff measurment and water proportional sampling. Water samples were analyzed for suspended solids, phosphorus and nitrogen after every rainfall event, or every day during snowmelt. The purpose has been to quantify erosion from agricultural areas and to find efficient farming practices to reduce erosion losses.
The results show great variation in runoff events, runoff volumes and runoff intensities for the catchments. In a two year period the number of runoff events varied between 17 and 44 and the runoff volumes between 30 and 300 mm. For planning of conservation practices and choice of tillage methods it is important to find catchments with high risk of runoff and erosion.
The greatest erosion losses were measured during winterperiods with rainfall on partially frozen autumntilled soil. No tillage and reduced tillage gave only small erosionlosses. Studies of hydrology in small catchments and event based erosionstudies seem necessary to determine the effects of different tillage methods.

INTRODUCTION

Soil erosion in Norway is mainly located in areas with marine sediments and cereal production. The dominating soil tillage has been autumn tillage, consequently, these areas are exposed to erosion during autumn and snowmelt. Plot studies started in 1982 by Njøs & Hove (1) have shown how different tillage methods strongly affect the soil loss. Erosion under different tillage systems were also measured by Lundekvam (2) in both plotstudies and in small catchments. He found that erosion on levelled land was much higher than on unlevelled land. He also showed the problems with upscaling from small plots to larger watersheds. In plot studies only sheet erosion an some rill erosion can be measured. Rill development after long slope lengths, deposition or erosion caused by consentrated waterflow in valley depressions, cannot be measured . Lundekvam (2) found that in some years rill erosion accounted for more than half of the soil loss in a catchment with a valley depression.
This project measured runoff and erosion from natural watersheds with different size and topograpy. The erosion measured by the outlet is a sum of all the erosion processes within the catchment. The study focused on how hydrology and tillage practices influence erosion.

MATERIALS AND METHODS

Runoff and nutrient leaching has been measured since 1986 in eight small catchments (0.3 - 3.2 ha) with different topography. Each catchment was instrumented for measurement of surface runoff and water sampling (fig.1). In one of the catchments , drainage water was also measured. Waterlevels were automatically recorded using a pressure transducer connected to a data logger. A mechanical limnigraph, recording waterlevel, was also installed. Volume proportional , mixed samples were taken with tipping buckets during every runoff event or every day during snowmelt. In addition time programmed samples were taken during substantial flow, especially during snowmelt and during the winterperiod. Total runoff were calculated and water samples were analyzed for suspended solids, nitrogen and phosphorus. Marine sediments with clay loam and silty clay loam were the dominating soils. Cereal grew in all catchments , but different tillage practices were either autumn ploughing, harrowing or no till cultivation , (table 1).

The water sampling was event based and controlled to avoid mixing of samples from before and after farming practices. From investigations where results are presented as total annual soilloss it cannot bee seen whether ruoff in autumn have occured before or after tillage. Specifically frequent sampling following changes in surface conditions were conducted to explain effects of different tillage operations.

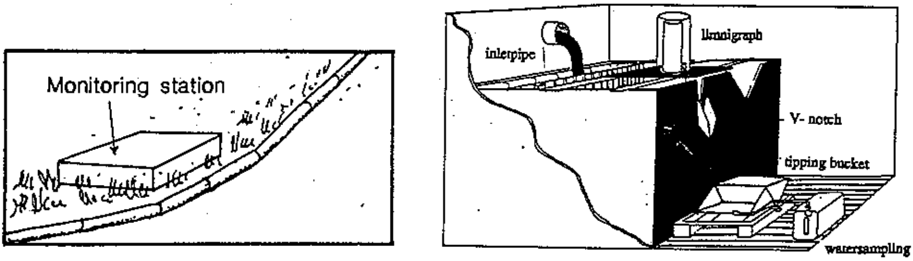
Field measurements and descriptions of erosion pattern were conducted in the catchments after major storm events. Within 3 of the catchments, 16 small plots ($1m^{2}$) were installed to study particle detachment and runoff. Physical soilparameters were analysed during the year ; shear strenght, aggregatestability and microtopography. Infiltrationtests and pF analysis were also included.

Particle movement to drainage system in clay soil was studied in one of the catchments. In addition to runoff measurement, tracerexperiment with infiltration of red dye , studies of cracks and soil stucture in profile and in soil cores by datatomograph were conducted.

Table 1. Soil tillage in autumn during 1987 - 1992.

Catchment	1987	1988	1989	1990	1991	1992
101, 103	no tillage	no tillage	ploughing	ploughing	harrowed *	no tillage
102	ploughing	ploughing	harrowed	harrowed	no tillage	no tillage
106,107	ploughing	ploughing	no tillage	ploughing	no tillage	meadow
108	ploughing	ploughing	ploughing *	ploughing	ploughing	no tillage

* and winterwheat.



Figur 1. Monitoring station for measurement of runoff and nutrient loss in small catchments.

PRELIMINARY RESULTS AND DISCUSSION

Hydrology

In some catchments runoff was mainly during snowmelt (on partially thawed soil), in other catchments also rainfall outside the winterperiod caused runoff (table 2). Watersheds with many runoff events or high runoff intensities have greater erosionrisk than areas with few runoff periods.

Table 2 . Number of annual runoff events (1987 - 1992).

Catchment	1987	1988	1989	1990	1991	1992	Total
101	8	9	3	6	7	8	41
102	14	23	13	13	20	22	105
103	0	0	3	8	7	6	24
106	20	24	16	20	29	29	138
107	28	29	16	17	31	14	138
108	11	18	8	10	19	12	78

In a two year period (87 and 88) the number of runoffevents varied between 17 and 44. The smallest catchments ,101 and 103, had also fewest runoff episodes. Catchment 106 had more than twice number of runoff events. The area was levelled land with heavy clay soil, with low infiltation capasity and compacted soil structure. Heavy rainfall, therefore, naturally cause surface runoff and also rapid drainage through cracks to drainage system.

Table 3. Total surface runoff (mm) 1987 - 1992. Station 107 is drainage water to catchment 106.

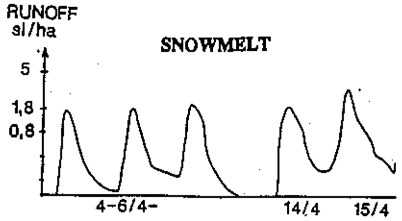
Catchment	1987	1988	1989	1990	1991	1992
101	33	102	71	127	31	*
102	88	97	30	128	29	36
103	0	0	10	121	27	*
106	238	292	178	216	242	88
107	357	404	123	54	165	93
108	188	327	130	232	244	146

* problems with data recording

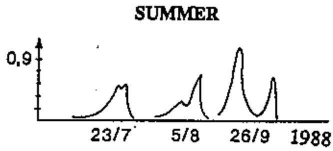
Table 4. Soil loss (kg / ha) 1987 - 1992.

Catchment	1987	1988	1989	1990	1991	1992
101	740	260		1520	80	*
102	520	150	30	1570	10	20
106	2020	1860	720	2630	570	200
107	3010	2760	1420	310	340	120
108	1120	400	200	4940	840	3580

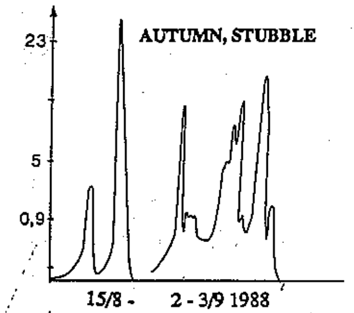
Catchment 106 had the highest erosion losses, both with surface runoff and to drainage water during years with autumnploughing (table 4). The latest years, 91 and 92 with no autumn tillage and meadow the erosion is reduced significantly.



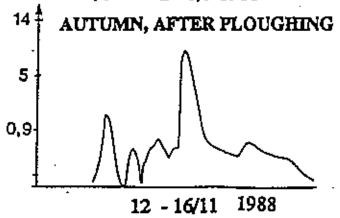
Date	Soil loss (mg/l)
4/4	630
5/4	936
6/4	1230
13/3	2500
14/4	3100
16/4	3915



Date	Soil loss (mg/l)
26/0	168



Date	Soil loss (mg/l)
15/8	776
2-3/9	245



Date	Soil loss (mg/l)
28/10	2715
12/11	2265
16/11	2858

Figur 2. Typical seasonal runoffpattern for catchment 106 (0,9 ha).

Figur 2 show a typical runoffpattern from catchments 106 of 0,9 ha. The area was ploughed in autumn. The highest erosion losses occured during snowmelt. The suspended solids in runoff was 3 - 4000 mg/l. In catchments with no autumn tillage, concentrations were mainly below 500 mg/l.

Heavy rainfall in summer and autumn caused runoffintensities even higher than during snowmelt. However it yielded small erosion losses because the area were in stubble before autumn tillage. The concentration in runoff from stubble areas were less then 700 mg/l.

After harrowing or autumn ploughing even small amounts of runoff gave high concentrations of suspended solids. Other years as 1990 and 1991 there were no runoff episodes after tillage and before snowmelt, consequently, the effect of tillage on erosion in autumnperiod could not be determined.

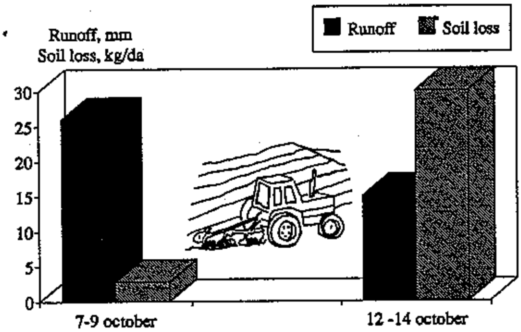
Tillage and erosion

Figure 3 shows an example of how autumn tillage affects erosion losses in catchment 108. During October,7-9 1987, 24 mm surface runoff gave a erosionloss of 2 kg/ha. The days after ploughing, October 12- 14 , the runoff was 15 mm, but the erosionloss had increased more than ten times (3).

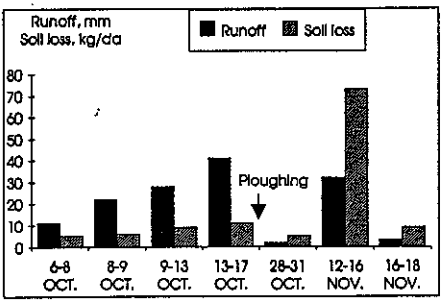
Catchment 106 was ploughed at the end of October. During mid-october episodes there were high runoff volumes but minimal erosion losses. After ploughing erosion losses were high with less runoff, the same pattern as for catchment 108 (fig.3).

To understand differences in soil loss between catchments it is important to know agricultural activity at a given time. Water samples from periods before and after ploughing must not be mixed.

Catchment 108



Catchment 106



Figur 3. Runoff (mm) and soilloss (kg/daa) for catchment 108 and 106 before and after tillage 1987.

Table 5. Runoff (mm) and suspended solids (mg/l) in surface runoff (catchment 106) and drainage water (catchment 107) before and after autumn ploughing 1987.

Date	Surface runoff (mm)	Suspended solids (mg/l)	Drainage runoff (mm)	Suspended solids (mg/l)
8 - 9/10	22.1	268	15.9	140
9 - 13/10	28.6	320	18.9	133
13 - 17/10	41.5	276	27.7	150
Ploughing				
17/10 - 2/11	2.0	2715	6.4	3800
12/11- 16/11	32.2	2265	33.4	4307
16/11- 23/11	3.0	2858	2.5	4184

Also, drainage water was affected by tillage, (table 5). In this catchment (106 /107) there was a similar pattern for loss of suspended material for both surface runoff and drainage water. Infiltration with red dye showed rapid water flow through cracks and backfill. Studies of soil structure in profile and in soil cores by datatomograph also showed a compacted soil structure

with cracks and macropores. Erosion to drainage water was strongly affected by soil tillage. In years with autumn ploughing 1987 to 1990 the maximum consentrations of suspended solids were more then 4000 mg/l. In years with no tillage or meadow the consentrations never exeeded 800 mg/l.
Similar results with particles to drainage water on drained clay soil on levelled land are reported by Lundekvam (3).

Soilerosion during winterperiod

The highest erosion losses were measured in the winter with rainfall on partially thawed soil, Example from catchment 108 (table 6). show that in january with no snowcover, rainfall gave runoff of 9 mm and a soil loss of 760 kg/ha. Then it became cold and the surface was ice covered. Snow fell on the ice covered surface and was then followed by rain. In a twoday period all the snowlayer and the rain 112 mm went away. The first day the runoff was from snow water with little particles, 25 mm runoff and only 2 kg/ha. The day after 77 mm surfacerunoff gave a soilloss of 3055 kg/ha. This was attributed to runoff from a upper unfrozen soil layer over frozen soil.
This example shows the great daily differences of runoff. Water sampling every day, combined with information about soil conditions and tillage, makes it possible to follow these processes.

Table 6. Precipitation , runoff (mm) and soil loss (kg / ha) for catchment 108 winter 1990.

	Runoff (mm)	Soil loss (kg/ha)	Precipitation (mm)
11 - 17/1			11.3
17 - 20/1	9	760	9.5
30- 31/1	25	2	81.3
31/1 - 1/2	77	3050	30.2
1/2 - 2/2	42	445	4.3
2/2 - 4/2	17	150	9.9

CONCLUSION

Studies of typical runoff pattern and hydrology in small catchments appear necessary to locate areas with high risk of runoff , erosion and nutrient losses.
Erosion studies on event basis are necessary for discussion of erosion from different tillage methods. No tillage and reduced tillage gave only small erosion losses.

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CHARACTERIZING SOIL TILLAGE AS A GEOMORPHOLOGICAL PROCESS

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ABSTRACT

Soil tillage is usually considered as a process having only an indirect influence on soil erosion. This paper describes the results of field experiments carried out with a mouldboard and a chisel plough showing that an important net downslope soil movement can be associated with soil tillage. The experimental evidence suggests that the soil redistribution by tillage can be described by a diffusion-type equation, which allows the intensity of the process to be characterized by a single number, which may be called the diffusion constant. The experimentally determined values of the diffusion constant vary between 100 and 400 kg m^{-1} $year^{-1}$: this implies that erosion and sedimentation rates associated with tillage may be more important than those associated with water erosion on much of the hilly arable land in Western Europe. Therefore, tillage should be considered as a soil degradation process *per se*, rather than a process which makes the soil more sensitive to erosion.

INTRODUCTION

Generally, soil tillage is considered as a factor affecting the soil's susceptibility to erosion by water: tillage has several short- and long-term effects on the soil's erodibility, which may, to a certain extent, counteract each other. The various effects of tillage operations on soil erosion by water have been studied experimentally and attempts have been made to quantify their effect on the soil's erodibility and the soil erosion process in general. Recent deterministic erosion models such as WEPP and EUROSEM take at least some of these effects into account (1,2)

On the other hand, the direct movement of soil by tillage operations has largely been neglected. This is rather surprising, considering the fact that in one mouldboard plough tillage operation c. 4000 t ha^{-1} of soil is moved. If during such a tillage operation a relatively small net movement occurs, the corresponding erosion and deposition rates will be high: a loss of only 0.25 % of the soil moved corresponds to an erosion rate of 10 t ha^{-1}.

In this paper, the results of a tillage experiment using both a mouldboard and a chisel plough are discussed. Using these experimental data, as well as those available in the literature, a universal approach to the modelling of soil redistribution by tillage is proposed, allowing the characterisation of the intensity of tillage redistribution by a single number.

MATERIALS AND METHODS

The experiments were carried out in June 1992 on the Huldenberg experimental slope, which has been described elsewhere (3). The south-facing slope is c. 150 m long, is basically convex, with a sharp basal concavity. The maximum slope gradient is c. 0.25 or c. 14 degrees. Soil texture is quite variable ranging form silty loam to loamy sand.

In order to study soil movement, numbered plastic spheres with a metal core and a diameter of 15 mm were used as a tracer. The spheres had a density of $\approx$1750 kg m^{-3}. The tracers were inserted on four strips of 1 m wide located on six transects. The spacing and location of the strips on the transects was such that one of them on each transect was tilled during a single up- or downslope tillage operation.

On each of the strips 10 holes 0.3 m deep were drilled at intervals of $\approx$0.1 m, a tracer was inserted in the hole and its location was precisely recorded using a automatic theodolite and a microprism. Next, a known quantity of fine, white sand was injected in the hole, filling the hole over $\approx$0.06 m, and the next tracer was placed and its position measured. This was repeated until the hole was completely filled, so that finally 5-6 tracers were placed in a single hole. As 10 holes were drilled, this resulted in a total of c. 60 tracers on each strip and 240 tracers on each transect, which were evenly spread over the whole depth of the plough layer.

After this, the experimental area was tilled one time in the up- or downslope direction, using two different implements, a mouldboard plough, with three blades having an internal spacing of 0.45 m and a chisel plough having a total width of 3.0 m and 13 teeth. For all operations, tractor wheel speed was maintained at c. 4.5 km h^{-1}. As six tracer strips on the six transects were positioned on a single tillage line, they were tilled in a single pass. This resulted in six tracer strips being tilled in each combination of tillage direction (up- or downslope) and tillage implement (mouldboard or chisel plough). Tillage depth of the mouldboard plough was $\approx$0.28 m, while, due to the dry soil conditions, the chisel plough only reached a depth of $\approx$0.12 m.

Immediately after the tillage operation, the plough layer was carefully excavated and the location of the displaced tracers was recorded. For every strip a tracer recovery rate of >90 % of displaced tracers was obtained. In order to calculate mean projected displacement distances, only data from the tracers located in the tilled layer were used. Also, no correction for the lost tracers was applied: this may result in an underestimation of the mean projected displacement distance, as it is rather likely that the missing tracers moved furthest.

RESULTS AND DISCUSSION

Data on soil movement by tillage can be analyzed by plotting the mean projected displacement distance of the tracers vs. the slope gradient (S, taken negative when the tractor moves in the downslope direction and positive when it moves in the upslope direction, (4)). Figures 1 and 2 show the results of our experiments. For both tillage implements the mean displacement distance is significantly related to slope gradient. This implies that there is a net downslope movement of soil by mouldboard as well as by chisel ploughing. A comparison of the slopes of the regression equations indicates that the slope effect on the displacement distance is slightly less important in the case of the chisel plough. However, when the two implements are compared, the depth of tillage has also to be taken into account.

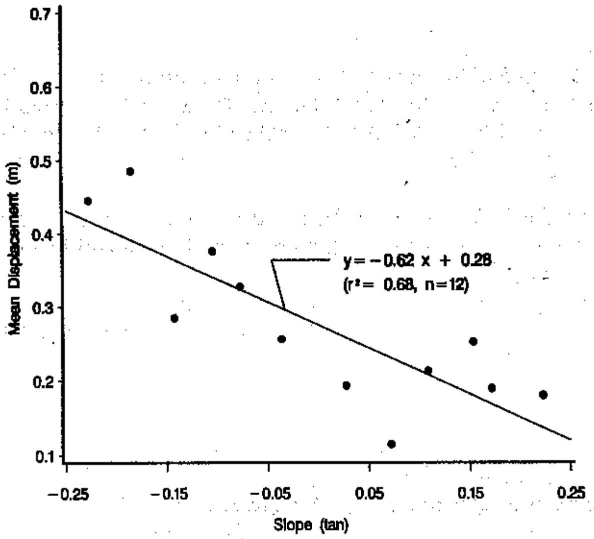

Fig. 1. Mean projected displacement distance vs. slope gradient (moldboard plough)

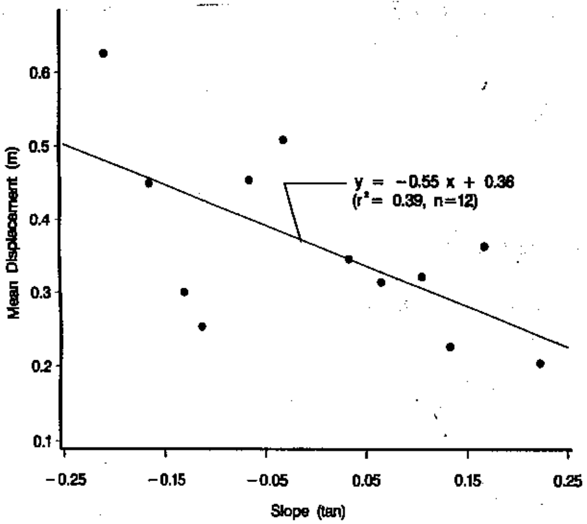

Fig. 2. Mean projected displacement distance vs. slope gradient (chisel plough)

These results raise the question as to how the intensity of soil redistribution by tillage may be quantified and modelled. Soil redistribution by tillage on a hillslope section of infinitesimal length and unit width may be described using the continuity equation for sediment movement on a hillslope:

$$\rho_b \frac{\partial h}{\partial t} = -\frac{\partial Q_s}{\partial x} \qquad (1)$$

where:

ρ_b = the bulk density of the soil (kg m^{-3})
t = the time (a)
h = the height at a given point of the hillslope (m)
Q_s = the flux of soil in the x-direction per unit of width (kg m^{-1} time^{-1})
x = the distance in the horizontal direction (m)

This equation can be solved if a suitable expression for Q_s is introduced. Both our data as well as those of (4) indicate that the relationship between mean displacement distance and the slope gradient may be approached by a linear function over the range of slopes studied (Figures 1 and 2). Thus:

$$\bar{d} = A + BS \qquad (2)$$

where:

$\bar{d}$ = the mean projected displacement distance in the up- or downslope direction (m)
S = the slope gradient, as defined by (4)
A,B = coefficients, obtained by regression analysis

On a single transect, one may calculate the net flux due to a single tillage operation by calculating the average of the flux during the up- and downslope movement of the tractor, taking into account the fact that the flux during upslope movement will be negative:

$$Q_s = \frac{D\rho_b\left[(A + B\frac{\partial h}{\partial x}) - (A + B(-\frac{\partial h}{\partial x})\right]}{2} \qquad (3)$$

where:

D = the tillage depth (m)

This implies that the net flux due to tillage may be written as:

$$Q_s = -k\frac{\partial h}{\partial x} \qquad (4)$$

where:

k = a constant, (kg m^{-1} time^{-1})
$= -D\rho_b B \qquad (5)$

The time period under consideration is in this case the time period between two consecutive tillage operations.

Equation (1) may then be rewritten as:

$$\rho_b\frac{\partial h}{\partial t} = k\frac{\partial^2 h}{\partial x^2} \qquad (6)$$

which is a diffusion-type equation (5). Soil redistribution by tillage may thus be considered to be a diffusion-type process. Other geomorphological processes which are often described using a diffusion-type equation are soil creep and direct downslope movement of soil by splash. The intensity of a diffusion-type process may be characterised by a single constant, k, which is also, in geomorphological literature, referred to as the diffusion constant. Equation (6) may then be solved using a finite-difference approximation and yearly time units. The value of k should then be representative of the yearly soil movement by tillage. Suitable values for k may be deduced both from our results as well as from those of others (4, 6, and 7, tab. 1).

Table 1 k-values derived from available experimental results. Note that the values are on a per tillage operation basis.

Tillage implement	Data source	k-value ($kg\ m^{-1}$)
Mouldboard plough, up- and downslope	this study	234
Chisel plough, up- and downslope	this study	111
Mouldboard plough, across slope	(4)	363
Mouldboard plough, up- and downslope	(4)	330
Moldboard plough, up- and downslope	(6)	263
Harrow, up- and downslope	(7)	78

The available experimental data indicate a rather narrow band of k-values associated with mouldboard ploughing using a mechanical tractor, whereby the data of (4) suggest that similar values apply for tillage up-and downhill and along the contourline. Soil redistribution due to chisel ploughing is less important especially when the depth of chiselling is limited. The k-values which were obtained imply that tillage is by far the most important diffusion-type process on arable land as k-values associated with soil creep and splash are of the order of 5-10 $kg\ m^{-1}\ a^{-1}$ (8).

CONCLUSIONS

The results of the present experiments clearly indicate that soil tillage is an important geomorphological process on arable land. Erosion and deposition rates associated with tillage erosion may often exceed 10 ton $ha^{-1}\ a^{-1}$, especially on irregular terrain. Such rates are at least of the same order of magnitude than average water erosion rates reported for hilly cropland in Western Europe. Therefore, soil tillage should be considered as an erosion process *per se* and not merely as an operation making the soil more vulnerable to water erosion. Thus, tillage is an important factor of soil degradation. At present, this is not well perceived: in the GLASOD (Global Assessment of Soil Degradation) project, soil erosion by tillage implements is not taken into account (9).

The available data indicate that soil redistribution by tillage may be described by a diffusion-type equation, similar to the expressions used to describe soil movement by creep and rainsplash. The intensity of such a process can be characterised by a single number, the diffusion constant (*k*). The available data suggest that the *k*-value for a mouldboard tillage operation is in the order of 200-400 kg m^{-1} per tillage operation: *k*-values associated with chisel operations seem to be lower.

The fact that soil movement by tillage may be described by a diffusion-type equation also implies a characteristic soil redistribution pattern: tillage erosion will take place on the convexities, while sedimentation will occur on the concavities. Absolute values of slope gradient and/or slope length, which are usually considered to be the dominant topographic controls on water erosion, are irrelevant for tillage erosion.

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Microscale effects of tillage and organic manure on infiltration and erosion of a crusting soil

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Abstract

In semi arid environments of Kenya, dominant soil types are structurally unstable, have crusting properties and frequent soil moisture deficits. Under these conditions, there is a need to understand how soil macrostructure (cloddiness), soil aggregation, soil compaction and surface soil crusting when affected by tillage and organic manuring would influence infiltration of rain water and available soil moisture. In this experiment, seasonal effects of tillage and farmyard manure applications on infiltration, runoff and soil loss of a crusting sandy clay loam soil (orthic Luvisol, FAO/UNESCO Classification, 1974) were investigated on microplots of size 2m² under marginal rainfall conditions. The plots were left bare (no test crop) to eliminate any influence of vegetative cover on pertinent hydrologic and soil properties.

The results obtained showed some significant changes in soil macrostructure (cloddiness) and soil aggregation with rainfall events and soil treatments. Soil crusting and subsequent compaction of the top soil layer increased with time and significantly reduced infiltration, profile soil moisture and soil loss but increased runoff within the experimental period. Soil shear strength and bulk density variations within the rainy season influenced soil erodibility and the moisture retention characteristics of the top soil. This study did prove the significant role of tillage and farmyard manure application in facilitating better infiltration rates, improving soil moisture, and reducing soil loss during the initial stages of the rainy season when there is no vegetative cover, the rainstorms are highly erosive and soil erosion is severe.

Introduction

In arid and semi arid lands (ASAL) environments of Kenya, where the Katumani experimental site is located, unreliable rainfall and problem soils constitute major constraints to crop and fodder production. The rainfall is often low and poorly distributed, occurs in high intensities of short duration and is highly erosive. The problems associated with the dominant soils of the area include structural instability, strong soil crusting and hardsetting and high erodibility. When exposed to erosive rainstorms, the soils generate high amounts of runoff and soil loss and have low infiltrability.

The development of rainfed agriculture for ASAL areas requires tillage and residue/manure management practices that protect these fragile and easily degraded lands from soil erosion. Tillage research conducted at Katumani (Marimi, 1978; Njihia, 1979; Muchiri and Gichuki, 1982; Kilewe and Ulsaker, 1983) found that conventional tillage, tied ridges, bench terraces, residue mulch and farmyard manure were sufficiently effective in controlling runoff through increased surface water storage, breakdown of soil surface crust, improved infiltrability and moisture retention characteristics of the soils. According to Njihia(1979), tied ridges effectively controlled runoff even from a maximum storm of 70 mm/day (with a return period of 3 years). In this experiment, a grain yield of maize was realized from tied ridged and stover mulch plots for a seasonal rainfall of 171 mm. Marimi(1978), observed that runoff occurred from convetional tillage treatments when rainfall exceeded 15 mm.

Traditional tillage and residue/manure management methods that are widely practised in Katumani, include residue mulching, tied ridging, conventional tillage (hand hoeing and Ox-ploughing), with and without farmyard manure and bench terracing. Additionally, conservation tillage methods like zero tillage (no till), terracing, cover cropping, intercropping, contour buffer stripping, have been used to optimize soil conditions for improved crop performance and yield. Most of these tillage operations involve high energy inputs (labour intensive, use of hand tools) both in construction and maintenance.

The applicability of these tillage practices depends on soil properties, climatic conditions, types of crops to be grown and socio economic conditions of the beneficiaries (smallholder farmers). For instance, contour bunds and ridges have proved to be very effective in areas where rainfall intensities and runoff rates are high. These structures are recommended for stable soils with surface sealing and crusting properties and low water intake rates. Contour bunds and ridges are expected to impound the runoff and increase the infiltration opportunity time of the soil. In conventional tillage, farmers use oxen or hand hoes to break the land upto a maximum depth of 20 cm - often leaving large soil clods at the surface. Often conventional tillage involves primary tillage operation with no secondary tillage until weed control. Minimum tillage operations often involve strip tillage (narrow strips of 20 cm width cut along the planting rows) or spot tillage (where planting holes of size 10 x 10 cm are made using hand hoes). Minimum tillage is also practised using the traditional slash and burn techniques. Contour buffer strips of widths of 1 to 2 m are often combined with contour ridges to check runoff and soil loss. Tied ridging at 2 to 3 m spacing along the furrows is usually done before the onset of the rains to avoid any breakages of ridges due to concentrated runoff flows. Crop residues are either placed on the soil surface (to dissipate rain energy and reduce surface sealing effects) or incorporated into the soil (ridges and furrows) as a means of supplementing organic matter deficiencies and improving the water holding capacities of soils. Farmyard manure (mixture of cowdung and grass/crop straw) is often applied in approprite quantities along furrows (in which seedlings are planted) to conserve soil moisture and enhance seedling emergence. At times the manure is applied in planting holes to create some favourable soil conditions for plant emergence and growth.

Materials and methods

The soil type at the experimental site was classified as a sandy clay loam orthic Luvisol. This soil was structurally unstable as depicted by a rapid breakdown in soil aggregation when exposed to intense rainstorm events. This instability was attributed to the inherent low organic matter contentof the soil.

This experiment was based on a completely randomized design. Each block was representative of the soil type and consisted of four treatments: conventional tillage(CT) using a forked hoe, zero tillage(ZT) with no manure, conventional tillage with 5 tonnes/ha of farmyard manure(5 FYM), conventional tillage with 10 tonnes/ha of farmyard manure(10 FYM). Each treatment was replicated three times. In each plot, infiltration and hydraulic conductivity, profile soil moisture, penetration resistance, shear strength measurements were taken using a disc permeameter, neutron probe, cone penetrometer and shear vane apparatus respectively. Profile soil moisture was monitored in each plot through two access tubes installed 30 cm from each plot end and to a maximum depth of 120 cm or lower depending on where the stone line was located. A runoff and sediment collection assembly consisted of a collecting trough, a PVC pipe, a 200 litre metallic drum and a 20 litre plastic container.

The neutron probe that was used at the site was calibrated for the 25-80 cm and 80-120 cm depth ranges (see Figure 1). The two calibrations were necessary because of the prevalence of iron concretions in lower soil horizons.

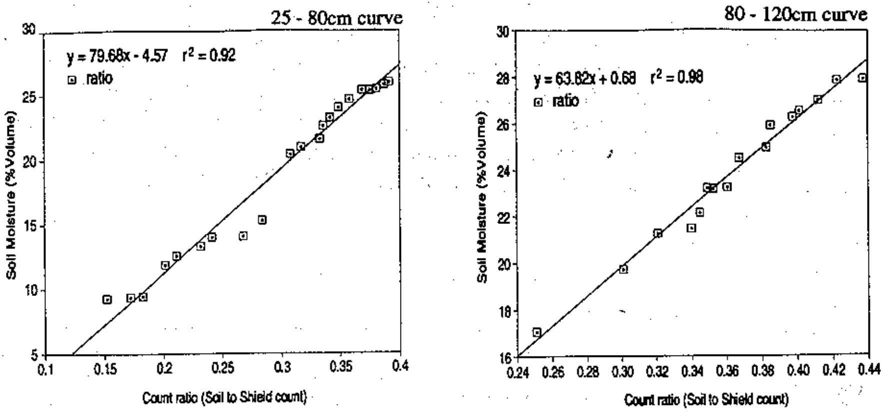

Fig. 1. Neutron probe calibration curves (25 - 80 cm; 80 - 120cm).

Collection of data involved soil moisture which was determined down the profile on a weekly basis in every plot using a neutron probe. Rainfall was recorded on a storm basis using two rain gauges (manual and recording) installed at the site. Rainfall intensity and distribution was obtained from the recording rain gauge. Runoff and soil loss were monitored on a storm basis. Bulk density was determined for two depth ranges of 0-15 cm and 15-30 cm at the beginning and at the end of every season. Penetration resistance was measured at selected time intervals within a rain season. Soil shear strength was measured on a weekly basis using a shear vane apparatus. Soil aggregate stability was determined using the wet sieving method. Infiltration after each rainstorm was taken as the difference between rainfall and runoff. The saturated hydraulic conductivity at the site was determined in situ using a disc permeameter. During each rainstorm, there was minimal evaporation since the relative humidity was high. After the onset of the rains, and subsequent breakdown in soil macrostructure, surface storage on the plots became negligible.

The analysis of collected data was conducted using two statistical methods, analysis of variance (ANOVA) and regression analysis. All these analyses were based on a 5% level of significance. The variables analyzed included; treatment, runoff, soil loss, infiltration and rainfall amount. The least significant difference (LSD) at 5% level of significance was used to determine the differences between the treatments.

Results and discussion

Bulk soil properties at site

Soil physical and chemical properties at the Experimental Site are given in Table 1. The soil properties considered included soil bulk density, soil textural composition and organic matter at various depths. An increase in clay down the profile was observed leading to textural changes from sandy clay loam to clay. The soil had a low organic matter content, decreasing with depth. The percentage of stable aggregates also decreased with depth possibly as a result of the decrease in soil organic matter. Soil bulk density decreased with depth and hence resulting in an increase in soil porosity down the profile. Bulk density of the soil ranged from 1420 kg m^{-3} in the top 15 cm to 1340 kg m^{-3} in the 60-100 cm horizon. The high bulk density in the top horizons was attributed to physical degradation (compaction) due raindrop impact. Changes in percent organic matter, bulk density and texture with depth were consistent with the changes in moisture characteristics for the different soil horizons.

Table 1

Soil properties at the experimental site.

Soil Profile Depth (cm)	Bulk Density kg m^{-3}	Soil Textural Composition			Organic Matter Content (%)	Textural Class
		Sand 2-0.05mm	Silt 0.05-0.002mm	Clay <0.002mm		
0-15	1420	67	5	28	1.6	SCL
15-35	1400	64	7	29	1.4	SCL
35-60	1370	57	8	35	0.7	SCL
60-100	1340	51	8	41	0.6	SC

Field capacity moisture varied from a maximum of 26% at the 0-10 cm depth to a minimum of 22% at the 30-60 cm depth (see Table 2). Maximum field capacity moisture was observed at the 10-30 cm depth (27%). The high field capacity moisture at the 0-30 cm depth was attributed to the high organic matter content relative to the other horizons.

Available soil moisture decreased with depth as a result of an increase in clay content down the profile. Thus the highest available water was in the 0-10 cm depth while the lowest was in the 60-100 cm depth.

Table 2

Soil Moisture Status in the Profile

Depth (cm)	Field Capacity (%)	Wilting Point (%)	Available Water (%)
0-10	26	9	17
10-30	27	13	14
30-60	22	11	11
60-100	24	15	9

Infiltration and moisture retention characteristics

After the onset of the rains, rainwater from the first eight storms infiltrated into the soil since there was no runoff. Under all treatments, infiltration was observed to decrease with time. The highest infiltration amount was observed under 10 FYM followed by 5 FYM, CT and ZT. The high volumes of surface runoff were attributed to the inherent low aggregate stability and subsequent surface sealing and crusting properties of the soil. No significant differences in infiltration between ZT and CT were observed.

Hydraulic conductivity varied from moderate to moderately rapid. The highest hydraulic conductivity values were observed under 10 FYM (70 mm/hr) while the least hydraulic conductivity was under CT (58 mm/hr). 5 FYM and ZT had hydraulic conductivities of 66 mm/hr and 57 mm/hr respectively. ZT had the least hydraulic conductivity followed by CT. More water was retained at saturation under CT (44%) than under ZT (41%). 5 FYM and 10 FYM retained 47% soil moisture at saturation.

Soil moisture held in the profile increased with depth at all suctions (see Table 3). This was consistent with the soil texture and bulk density changes with depth. Clay content was highest at lower horizons while sand content was highest in the top 0-15 cm. The high water holding capacity of clay did explain the high water content held at lower soil horizons (40.6% clay and 51.4% sand) as compared to the 0-10 cm soil depth (27.9% clay and 67.2% sand).

Table 3

Profile soil moisture release characteristics of a Luvisol.

Depth	% Volumetric Moisture Content						
	Suction (bars)						
	0.00	0.10	0.50	1	5	10	15
10	40	33	26	15	12	11	9
30	43	29	22	16	13	12	11
60	45	34	27	17	15	14	13
100	47	38	24	20	16	16	15

At low suctions (0.1 bars), there was more water held in the FYM treatments than the other treatments. At high suction (15 bars), the treatment differences in soil moisture became negligible. Thus the effect of farmyard manure on soil moisture release characteristics decreased at high suctions (see Table 4).

Table 4

Treatment soil moisture release characteristics.

Treatment	% Volumetric Moisture Content						
	Suction in Bars						
	0.00	0.10	0.50	1	5	10	15
10 FYM	46	35	22	22	20	18	13
5 FYM	44	34	21	20	18	17	14
CT	41	32	20	20	17	15	14
ZT	41	31	18	17	16	15	14

Soil moisture and bulk density

The trend of soil moisture in the top soil depth (0-10 cm) was more or less similar under all treatments (see Figure 2), though the seasonal soil moisture kept on fluctuating as a result of wetting due to rainfall and drying during the dry spells. Variation of soil moisture with time was more pronounced in the 0-10 cm range as compared to the 0-100 cm range. In both depth ranges, the highest soil moisture content was observed under 10 FYM followed by 5 FYM, CT and ZT. The soil moisture down the profile was lowest at the onset of the rains possibly as a result of the previuos dry season (May to October). Under all treatments, the peak profile soil moisture was observed in January coinciding with the period of maximum rainfall.

Down the profile (0 - 100cm), maximum soil moisture was observed under 10 FYM, followed by 5 FYM, CT and ZT. As the short rains season continued, the differences in soil moisture between CT, ZT and 5 FYM became negligible (see Figure 3). Soil moisture down the profile was lowest at the onset of the rains. This was attributed to the past dry season (April to October). Field capacity moisture conditions (248 mm in the first metre depth) were never reached even in January when 270 mm of rainfall were received. This was attributed to the high runoff generated from the bare runoff plots. Evaporation from the surface could also have contributed to the soil moisture deficit. Despite the low profile soil moisture within the study period, crop performance in the area was very good and farmers had bumper maize/bean harvests.

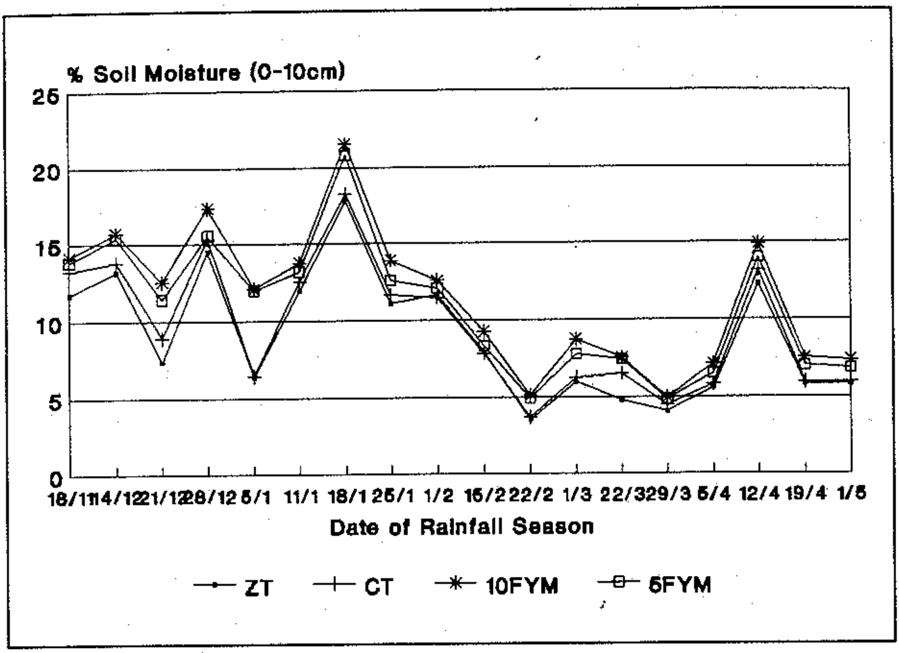

Fig. 2. Seasonal variation in soil moisture (0-10 cm), 1992/93.

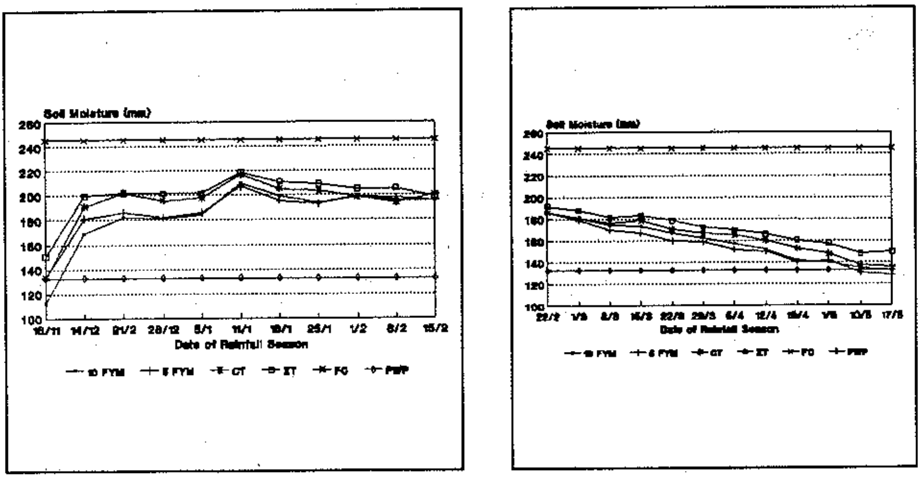

Fig. 3. Treatment effects on profile soil moisture (0-100 cm).

The observations in profile soil moisture were consistent with the observed trends in treatment runoff. The high soil moisture content under 10 FYM and 5 FYM can be attributed to the addition of farm yard manure. Farmyard manure improved soil aggregation and hence increased the water retention capacity of the soil.

During the study period, the highest bulk densities were observed under ZT followed by CT, 5 FYM and 10 FYM (see Figure 4). The high bulk density observed under ZT can be attributed to soil compaction as a result of rain drop impact. The relatively low bulk density under 5 FYM and 10 FYM can be attributed to the incorporation of farmyard manure into the soil.

For all treatments, the least bulk density was observed on 15/2/93 after 91 mm rainfall had been received in a period of eight days with a dry spell of only one day. The highest bulk densities were observed at the end of the study period. During the long rains period, the soil moisture was fairly low because the rainfall was sparsely distributed and of low amounts.

Generally, soil bulk density tended to increase under low moisture conditions (end of season) and to decrease under high soil moisture (after a rainstorm). High bulk density is known to impede root growth leading to poor water and nutrient extraction from deep soil horizons. It also leads to inadequate aeration and subsequently to poor crop performance.

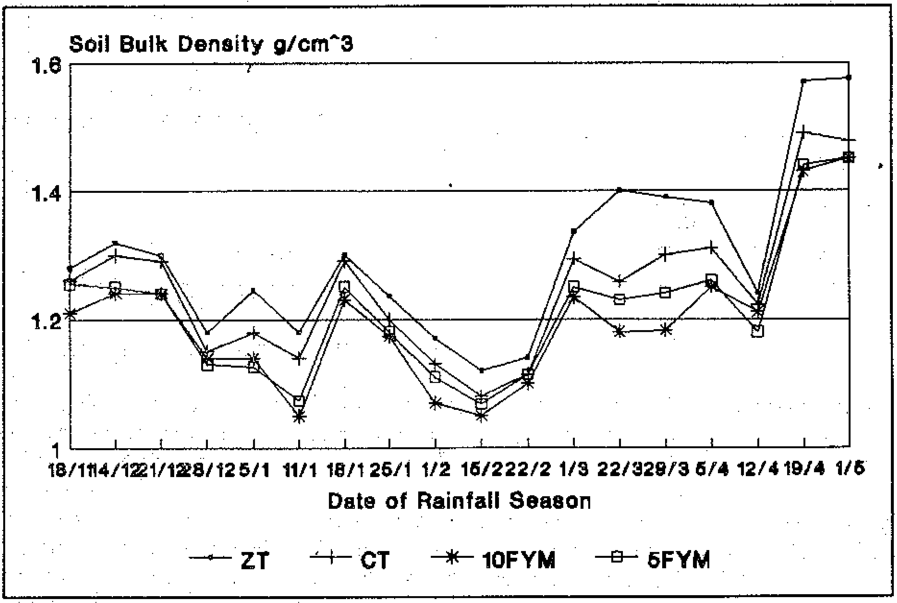

Fig. 4. Seasonal variation in bulk density, 1992/93.

Soil shear and crust strengths

The highest values for soil shear strength were recorded at the beginning of the season (see Figure 5). During the experimental period, soil shear strength under ZT remained relatively higher than under the other three treatments.

Though seasonal variations in soil shear strengths were observed, they were less pronounced when compared to variations in bulk density and soil moisture content. Bulk density and soil shear strength tended to follow a similar trend, bulk density increasing when soil shear strength was increasing and vice versa.

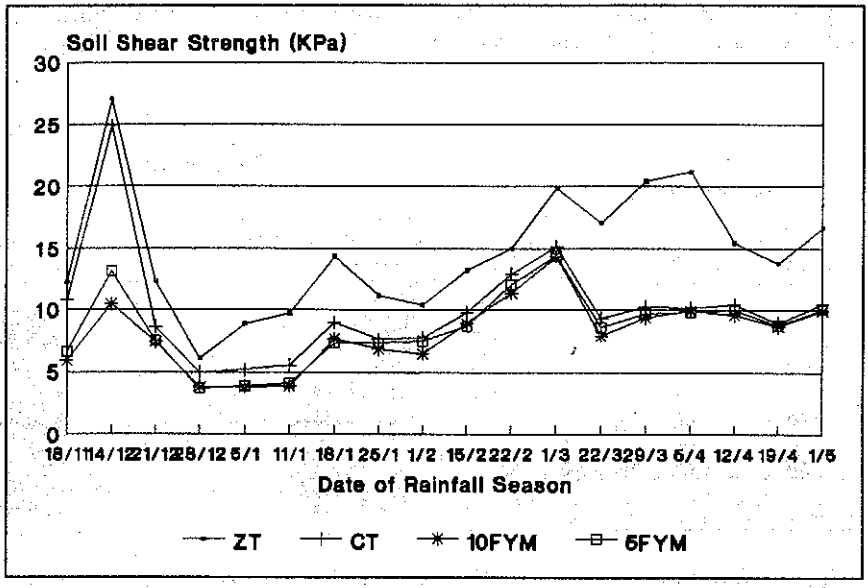

Fig. 5. Seasonal variation in soil shear strength, 1992/93.

Given the low aggregate stability of the soils, surface sealing and subsequent crusting did occur especially after high energy storms. A storm of 46 mm received on 13/3/93 nearly destroyed all the clods in the treatments. The breakdown in soil macro structure resulted in surface sealing and crusting.

Resistance to penetration was found to be highest under zero tillage followed by conventional tillage, 5 FYM and least under 10 FYM. Penetration resistance was influenced by soil moisture. The first penetrometer readings were taken on 2/4/93 after a storm of 12 mm on 1/4/93. It was at this time that the lowest resistance to penetration was recorded. Penetration resistance increased steadily and peaked on 12/4/93 for all treatments. On 18/4/93, a decline in resistance to penetration was observed for all treatments. This could have been as a consequence of the 3 mm and 20 mm of rainfall received on 16/4 and 17/4/93 respectively (see Figure 6).

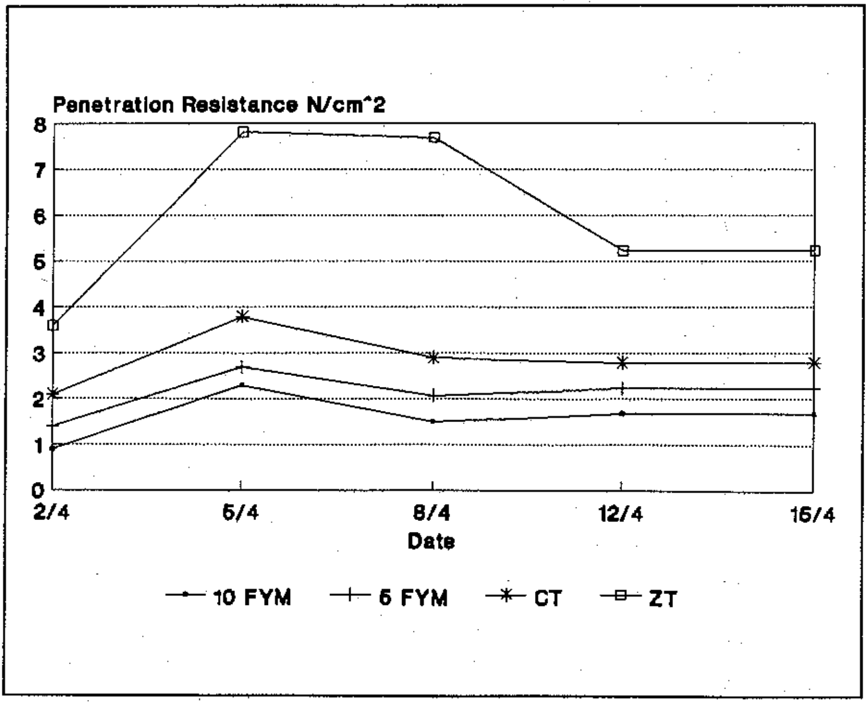

Fig. 6. Treatment differences in penetration resistance, 1993.

Soil organic matter content and aggregate stability

Soil organic matter under all treatments was very low (see Table 5). This could have been the cause of the low stability of aggregates observed. As expected, the highest amount of organic matter (1.7%) was found in the soil where 10 tonnes of farmyard manure had been applied followed by 5 FYM (1.6%), CT (1.6%) and ZT (1.5%).

By the end of the season, organic matter under all treatments had decreased, the highest decrease being under conventional tillage treatment. The decline in organic matter under was largely attributed to the high quantities of top soil that were lost through runoff. The high temperatures at the study area could have also contributed to loss of organic matter through oxidation.

The percentage of stable aggregates ranged from 26% (10 FYM) to 11% (CT). The percentage of stable aggregates under 5 FYM was 20% while that under ZT was 12%.

Table 5

Seasonal treatment differences in soil organic matter content, 1992/93

Treatment	Initial Organic Matter(%)	Final Organic, Matter(%)	% Reduction in Organic Matter
10 FYM	1.7	1.6	0.1
5 FYM	1.6	1.5	0.1
CT	1.6	1.4	0.2
ZT	1.5	1.4	0.1

The low stability of aggregates was attributed to the low organic matter content of the soil observed at the site. The relatively high aggregate stability under 10 FYM and 5 FYM was attributed to the addition of farmyard manure which led to increased soil organic matter content. If soil aggregation is improved, the breakdown of soil clods can be reduced. In this way a rough surface can be maintained especially during the initial stages of the season. This would then facilitate depressional storage and hence increase the infiltrability of the soil and decrease runoff and soil loss.

Seasonal Variability in Rainfall

Recorded storm rainfall varied between 0.5 mm and 70 mm with a mean of 12 mm and standard deviation of 17 mm. The highest amount of monthly rainfall was received in January (269 mm). This rainfall was five times as much as the long term mean of 50 mm for that month (see Figure 7). Over the experimental period, the maximum storm duration recorded was 10 hours and 48 minutes with a rainfall amount of 24 mm while the minimum storm duration was 6 minutes and a rainfall amount of 1 mm. The mean storm duration was 2 hours and 30 minutes.

From October to December, a total rainfall amount of 404 mm was received and this was much higher than the seasonal average of 286 mm (27 years record). The total rainfall received in the short rains period of October 1992 - February 1993 was 767mm compared to the 27 years mean of 379 mm (see Figure 7). During the study period, the short rains peaked in January 1993 and not in November as expected. The month of April, which is often the peak of the long rains received only 38 mm of rainfall, far below the monthly average of 144 mm (27 years record).

During the short rains period, the rainstorms were well distributed. It was raining continuously for several days after an interval of two to seven days during the first 35 days (see Table 6). Towards the end of the crop growing season (February), the rains that fell were not utilized by the crop which had dried and was being harvested. Nevertheless, the farmers reported having had the highest maize/bean yields in a period of ten years.

Table 6

Distribution of seasonal rainfall, 1992/93

Date	Days of consecutive rainfall	Rainfall (mm)
28/10 - 1/11	4	10
3/11 - 6/11	4	38
11/11 - 15/11	5	41
17/11	1	1
23/11 - 25/11	3	10
28/11 - 1/12	4	84
7/12	1	4
9/12	1	7
11/12 - 12/12	2	75
14/12	1	7
17/12 - 19/12	3	81
28/12 - 2/01	6	38
6/01 - 10/02	5	49
13/1 - 21/01	9	143
23/1	1	10
26/1 - 1/02	7	78
8/2 - 12/2	5	84
14/2 - 15/2	2	7
13/3	1	46
15/3	1	2
19/3	1	2
23/3 - 24/3	2	7
1/4	1	12
16/4 - 17/4	2	22
19/4	1	4
6/5	1	9
12/5	1	4

At the onset of the long rains period, a storm of 46 mm received on 13/3/93 completely destroyed the soil clods of freshly tilled plots. This was the first rainstorm of the season and it contributed 60% of the erosive rainfall for that period. This was the most intense and erosive rainstorm observed during the entire experimental period.

Over the long rains season, the rainfall received was not adequate and hence all the crops planted wilted and dried up. Soon after planting on 15/3/93 upto 31/3/93 (18 days), only 12 mm of rainfall was received, giving the crops a poor establishment. From March to May, only 103 mm of rainfall were recorded as compared with a mean of 297 mm (27 years record). Rainfall kept on reducing progressively from January to May. In May, 13 mm were received whereas the mean monthly value is 65 mm. There were no rains recorded after the month of May.

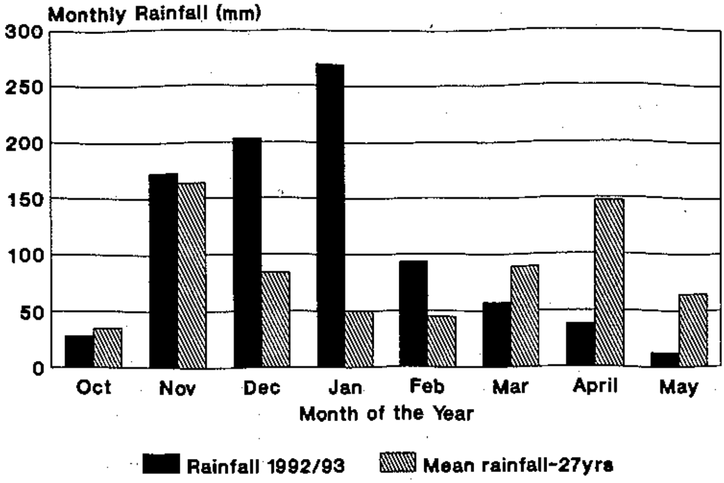

Fig. 7. Comparison of seasonal (1992/93) with long term (27 years record) rainfall distribution.

Rainfall Events and Distribution

The highest number of rainfall events in any one month was recorded in January (23 events) while the least was recorded in May (2 events). For the other months, the number of rainfall events was as follows: October (3), November (17), December (23), February (8), March (5), April (4) and May (2).

From October 1992 to March 1993, there were 69 rainy days over a 151 days period while from October to May there were 75 rainy days over a 200 days period. The period of March to May had only 11 rainy days stretched over a 61 days period.

During the first 40 days of crop establishment, which is a vegetative growth stage, most crops are sensitive to soil moisture deficits. In this long rains period, a total rainfall amount of 95 mm had been received. Except for an initial storm of 46 mm, the rest of the rainfall was low and thinly distributed. Hence the maize crop planted in the adjacent area experienced a very serious soil moisture shortage, and hence dried up. Consequently, no maize/bean crop was realized in the area during the long rains period.

Total rainfall in the short rains season of as little as 155 mm (1981) and as much as 925 mm (1961) has been recorded. On the other hand, total rainfall in the long rains season of as little as 133 mm (1973) and as much as 660 mm(1979) has been observed (Stewart and Faught, 1984).

Storm Intensity, Energy and Erosivity

The product EI_{30} (Wischmeier's erosivity index) was used as an index of storm erosivity in this study. Where E is the total storm kinetic energy and I_{30} is the maximum 30 minute intensity.

I_{30} varied from 46 mm/hr to 0.5 mm/hr with a mean of 8 mm/hr while storm kinetic energy varied from zero to 1360 J/m^2. Coefficients of correlation varied from 0.76 between I_{30} and rainfall and 0.40 between I_{30} and storm duration. The correlation coefficient obtained between kinetic energy (KE) and rainfall amounts was 0.94. Correlation coefficients between KE and runoff (0.92) and KE and soil loss (0.89) were also high. Other correlation coefficients of 0.71 and 0.80 were obtained between I_{30} and runoff and I_{30} and soil loss respectively. These coefficients increased to 0.79 and 0.84 respectively when I_{30} was multiplied by the total storm energy, E. These observations confirmed that EI_{30} is a better index of erosivity than either E or I_{30}.

Coefficients of determination were higher between I_{30} and soil loss than between I_{30} and runoff. The coefficient of determination (r^2) between I_{30} and runoff for the various treatments were 0.55 (CT), 0.48 (10 FYM), 0.49 (5 FYM) and 0.57 (ZT). For I_{30} and soil loss r^2 values were 0.72 (CT), 0.66 (10 FYM), 0.65 (5 FYM) and 0.64 (ZT) while for EI_{30} and soil loss, they were 0.86 (CT), 0.67 (10 FYM), 0.68 (5 FYM) and 0.71 (ZT).

Rainfall and Runoff Response

There was a strong positive correlation between rainfall and runoff (r = 0.94) implying that rainfall amounts strongly influenced runoff. The best predictors of runoff were rainfall amounts and total storm kinetic energy with regression coefficients ranging between 0.94 and 0.84 for the four treatments. From initially dry soil conditions, rainfall amounts less than 6 mm never caused runoff. There was a storm of less than 5 mm that caused runoff just as there were storms of more than 5 mm that never caused runoff indicating the significance of antecedent moisture content, soil surface conditions and rainfall characteristics in influencing the occurrence of runoff.

The influence of rainfall amount on runoff was greatest under CT (r^2 = 0.93) followed by ZT (0.92), 10 FYM and 5 FYM (0.89). The influence of kinetic energy on runoff was also highest under CT (0.90) and least under 10FYM (0.84).

I_{30} coefficients of determination (r^2) with runoff were 0.72(ZT), 0.66(CT), 0.59(5 FYM) and 0.57(10 FYM). Therefore rainfall amount influenced runoff more than I_{30}. This was attributed to the many rainfall events of low intensity, high amounts and long duration that caused runoff. Many rainfall events occurred intermittently over several hours. During prolonged storms, rainfall intensity might be low but because of the duration, saturation results leading to runoff. In such a case rainfall amount would be a better estimator of runoff as compared to rainfall intensity. I_{30} would therefore be good for intense rainfall events of short duration and high amounts.

Table 7

Runoff expressed as a percentage of erosive rainfall, 1992/93.

Date	Rainfall (mm)	Treatment (% Runoff)			
		CT	10FYM	5FYM	ZT
12/11	16	33	4	6	46
15/11	17	35	11	15	45
28-1/12	84	64	37	40	75
9/12	7	14	6	8	15
11/12	67	70	62	64	75
12/12	7	17	13	14	20
17-18/12	75	64	47	49	67
19/12	5	58	46	47	64
31/12	17	25	15	18	31
7/1	24	3	2	2	3
10/1	11	37	13	15	65
14/1	17	18	14	15	32
16/1	37	49	32	35	58
17/1	3	18	10	12	21
18/1	11	16	11	11	26
20/1	38	60	53	55	67
28/1	10	41	24	26	49
30/1	52	65	56	63	73
8-9/2	50	28	19	21	32
11/2	30	47	39	38	52
13/3	46	68	49	56	87
1/4	12	26	24	23	41
17/4	20	31	28	28	34
Mean runoff (%)		39	27	29	47
Total Runoff (mm)		326	238	255	379

There were no significant differences in runoff between the two tillage treatments. However the two treatments had much higher runoff when compared to the farmyard manure treatments. The differences in amounts of runoff between the four treatments were negligible for small storms but significant for large storms.

The occurrence of runoff was influenced by the interval between storms. The shorter the interval, the more the runoff. When there had been a large storm the previous day (above 37 mm), even a small storm of 3.5 mm caused runoff. Whereas when there had been a dry spell of two days, rainfall of 13 mm never caused runoff.

There was a noticeable trend between runoff and rainfall during the experimental period. When rainfall amounts were high, the amount of runoff and soil loss was also high. While low runoff and low soil loss were observed under small storms. When Kilewe and Ulsaker (1984) related total kinetic energy to rainfall amounts for the storms in Katumani, the resulting relationship had an r^2 of 0.97 indicating that nearly all variations in total kinetic energy can be accounted for by rainfall amount.

Total runoff expressed as a percentage of erosive rainfall during the duration of the study was 47 (ZT), 39 (CT), 29 (5FYM) and 27 (10FYM) (see Table 7).

Storm Runoff

Though the first storm was received on 28/10/1992 it was not until 12/11/1992 that runoff was observed. Throughout the season, 75 rainfall events of various magnitudes were received but only twenty five caused runoff. The first nine storms never caused any runoff or soil loss and they totalled upto 70 mm. This can be attributed to the fact that they were small in magnitude, spread over long time durations and occurred at the time when the soil was dry following the dry season.

The initial results did not reflect significant treatment differences in runoff between 5 FYM and 10 FYM though there tended to be less runoff under the latter treatment (see Figure 8 and Table 8).

Table 8

Treatment differences in seasonal runoff, 1992/93.

	Rainfall (mm)	(Runoff mm)			
Year and Season		ZT	CT	5FYM	10FYM
1992 Short rains	767	327(a)	286(a)	221(b)	207(b)
1993 Long rains	108	52(a)	40(b)	34(c)	31(c)
Total	875	379(a)	326(b)	255(c)	238(c)

Values with the same letter in parenthesis were not significantly different at P (0.05).

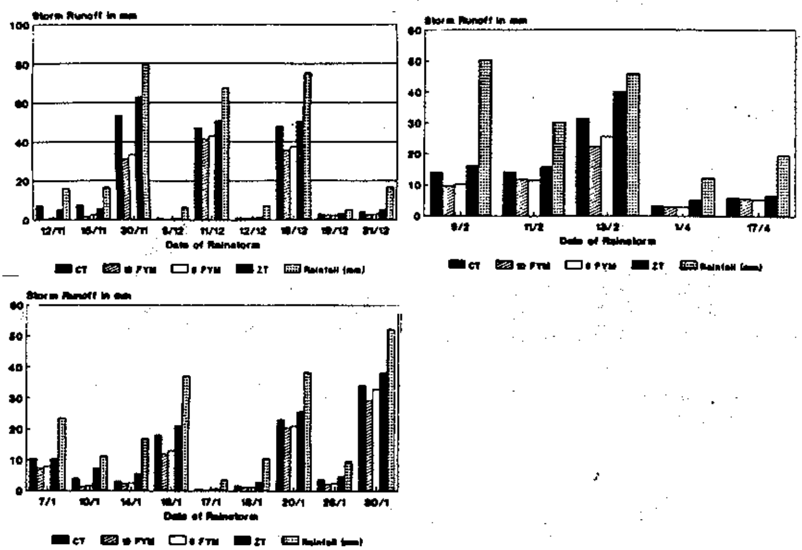

Fig. 8. Seasonal treatment differences in storm runoff, 1992/93.

Storm soil loss

The highest amount of soil loss was observed under conventional tillage followed by zero tillage, 5 FYM and 10 FYM (see Figure 9 and Table 9). The amount of soil loss during the study period was 18.6, 14, 12.4 and 11.5 kg/m^2 under conventional tillage, zero tillage, 5 FYM and 10 FYM respectively. More soil was lost during the short rains as compared to the long rains due to the many rainfall events that occurred in the short rains period.

The initial storms never caused runoff and soil loss. This was attributed to the low initial soil moisture conditions and high infiltrability of the soil. Light rainfall facilitated erosion by loosening the soil surface such that the loosened soil particles were then easily washed away by the next runoff event.

On a storm basis, the lowest and highest amounts of soil loss in the two rain periods were experienced on 9/12/93 (6.5 mm) and 13/3/93 (46 mm) respectively. The soil loss on 13/3/93 was as follows: 2.7 kg/m^2 (CT), 2.2 kg/m^2 (ZT), 1.5 kg/m^2 (10 FYM) and 1.5 kg/m^2 (5 FYM). The duration of the storm was one hour and the total kinetic energy was 1236 J/m^2. The high amount of soil loss was attributed to the fact that the land had just been tilled and the storm was very erosive (56540 Jm^{-2} mm hr^{-1}).

There was good correlation between soil loss and storm kinetic energy (r^2 = 0.9). Therefore kinetic energy did significantly influence soil loss. Soil loss was also influenced by runoff (r^2=0.74) and rainfall amount (r^2=0.71).

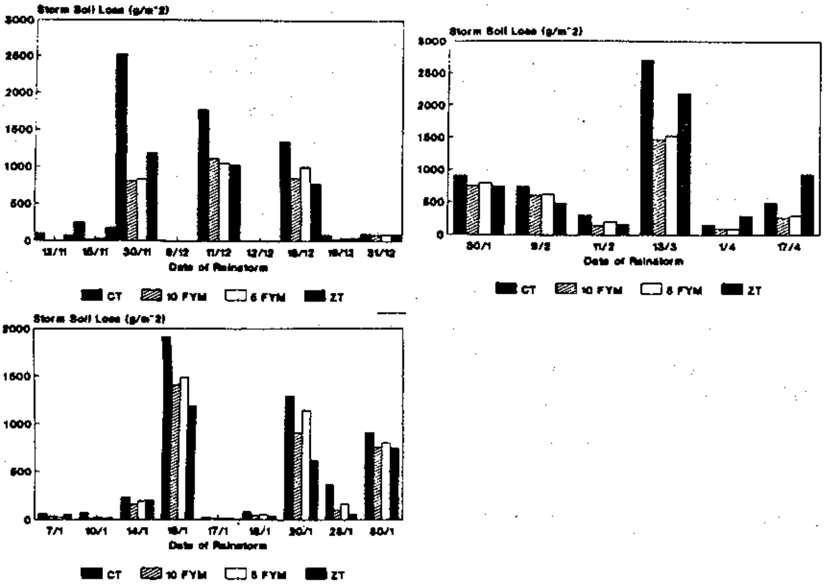

Fig. 10. Seasonal treatment differences in storm soil loss, 1992/93.

Table 9

Treatment differences in seasonal soil loss, 1992/93.

	(Soil loss g/m^2)			
Year and Season	ZT	CT	5FYM	10FYM
1992 Short rains	9518	14770	10038	9346
1993 Long rains	4478	3874	2373	2162
Total	13996	18644	12411	11508

Table 10

Storm rainfall and treatment soil loss, 1992/93

Date	Rainfall (mm)	Soil loss (gm/m²)			
		CT	10FYM	5FYM	ZT
12/11	16	106.3	1.8	4.0	79.9
15/11	17	251.6	21.6	25.0	177.5
28-1/12	84	3335.8	1368.4	1448.3	1732.0
9/12	7	4.5	0.5	0.9	2.1
11/12	67	1980.1	1469.3	1502.6	1512.4
12/12	7	17.1	5.3	5.5	4.2
17-18/12	75	1514.3	814.6	1152.1	910.0
19/12	5	149.6	49.4	58.7	78.6
31/12	17	106.1	85.8	89.6	103.5
7/1	24	120.0	9.8	17.5	112.4
10/1	11	81.0	10.4	19.5	13.6
14/1	17	257.0	160.3	192.5	196.8
16/1	37	2130.8	1802.1	1898.0	1695.7
17/1	3	19.9	12.2	12.8	12.9
18/1	11	101.4	83.8	84.6	65.6
20/1	38	1834.7	1635.2	1636.7	70.3
28/1	10	475.6	108.3	136.6	62.2
30/1	52	1128.0	931.7	932.1	940.4
8-9/2	50	720.3	583.3	633.9	651.2
11/2	30	436.6	192.0	187.1	196.6
13/3	46	2697.1	1460.2	1521.3	2174.6
1/4	12	261.8	86.7	213.1	610.6
17/4	20	914.8	615.1	638.5	1693.3
Total Soil loss (g/m²)		18644.4	11507.8	12410.9	13096.4

For small storms, the differences in soil loss were small and hence negligible. On the whole, the amount of soil loss was high (for heavy storms) irrespective of treatments and time. As the season progressed, soil loss under zero tillage became markedly reduced to the extent that it was at times less than that lost under 10 FYM or 5 FYM. Soil loss under conventional tillage remained consistently higher than that under ZT, 10 FYM and 5 FYM throughout the season. Variations in soil erosion can be attributed to compaction of the soil surface and surface sealing and crusting (due to intense rainstorms). Although tillage can facilitate the breakdown of soil crusts and enhance infiltration, it can also lead to high soil loss as was observed in this study.

Conclusions and Recommendations

Conclusions

Soil properties

The infiltrabilty of the soil improved with the application of farmyard manure which increased the stability of aggregates. Besides, the maintenance of a cloddy soil macrostructure through tillage, helped to impound runoff in depression storage and hence enhanced infiltration. Some seasonal decrease in infiltration was attributed to surface sealing and crusting of the top soil which resulted in high volumes of surface runoff.

Seasonal soil moisture variations were more pronounced in the 0-10 cm depth than the 0-100 cm depth. The differences in soil moisture between treatments (0-10 cm) were not significant at the onset when infiltrability was enhanced by depressional storage and the end of the season when treatment effects were neglible. The highest soil moisture was observed under 10 FYM followed by 5 FYM, CT and ZT . This did prove that FYM application was effective in enhancing soil moisture storage. Under all treatments, field capacity moisture conditions were never reached during the experimental period.

Soil bulk density was highest under ZT and CT but least under the farmyard manure treatments. Bulk density was low when soil moisture was high and high under low soil moisture conditions.

Penetration resistance and soil shear strength were highest at the beginning of the season when the profile was still dry. The highest values were recorded under ZT indicating a need for soil tillage soon after harvest when there is still some residual soil moisture. Penetration resistance was least under the farmyard manure treatments.

Soil aggregation improved with the application of farmyard manure. At the end of the rains, there was a reduction in soil aggregation for all treatments. The highest decrease was in CT and ZT. This was attributed to the decrease in soil organic matter content due to top soil losses and organic matter oxidation as a result of high temperatures at the experimental site.

Seasonal Rainfall

In the two rain seasons, there was a strong correlation between storm kinetic energy, runoff and soil loss. High erosivity led to increased soil erosion. Rainfall of low amount spread over long duration never caused runoff while high rainfall over short durations was highly erosive.

The short rains of 1992/93 were longer than usual and peaked in January 1993 with 35% of the seasonal rainfall. The longterm peak month of the short rains is November. The seasonal rainfall of 767 mm for the short rains period was much higher than the longterm average of 378 mm. Runoff during the month of January was 43% (ZT), 37% (CT), 28% (10 FYM) and 31% (5 FYM) of the month's total rainfall. During the short rains period, the most erosive storm of 84 mm resulted in a soil loss of 3.3 kg/m^2 (CT), 1.7 kg/m^2 (ZT), 1.5 kg/m^2 (5 FYM), 1.4 kg/m^2 (10 FYM) and runoff of 75% (ZT), 64% (CT), 40% (5 FYM) and 37% (10 FYM).

During the long rains period, April, which is usually the peak of the long rains, received only 38 mm of rainfall far below the monthly mean of 147 mm. The most erosive storm of 46 mm was received at the onset of the long rains and resulted in soil loss of 2.7 kg/m^2 (CT), 2.2 kg/m^2 (ZT), 1.5 kg/m^2 (5 FYM) 1.5 kg/m^2 (10 FYM) and runoff of 87% (ZT), 68% (CT), 56%(5 FYM) and 49% (10 FYM).

Generally in the two rain seasons, the first storms were small in magnitude, spread over long time durations and of low intensities and consequently could not cause runoff and soil loss. In the short rains period, which received 64 storms, 20 erosive and 25 above 9 mm and well and evenly distributed, the farmers had a bumper harvest. Over the long rains period, in which eleven storms were received, eight of them below 9 mm, there was poor crop performance and this resulted in a complete crop failure.

Surface Runoff

Storm runoff was influenced by rainfall intensity, rainfall amount, antecedent moisture content and storm duration. Surface runoff was strongly influenced by rainfall amount under all treatments. Under high soil moisture conditions, storms of less than 5 mm caused runoff while under initial dry conditions (onset of rains), storms greater than 15 mm never caused runoff. There was no significant difference in runoff between CT and ZT but the two treatments resulted in much higher runoff than farmyard manure treatments. Treatment differences in runoff were negligible for small storms.

At the beginning of the season, the initial cloddy surfaces due to soil tillage enhanced depression storage and hence the absence of runoff and soil loss. With time, there was an increase in soil sealing, crusting, and compaction (due to raindrop impact coupled with the inherent low organic matter content) which contributed to the high runoff volume observed in zero tillage. Farmyard manure application was able to significantly reduce runoff when compared to conventional tillage with no manure and zero tillage. The farmyard manure in the soil led to an increase in water holding capacity and a reduction in soil surface sealing and crusting. Runoff expressed as a percentage of seasonal rainfall was 43%, 48% (ZT), 37%, 37% (CT), 29%, 31% (5 FYM) and 27%, 28% (10 FYM) during the short rains and long rains period respectively.

Soil Loss

Soil loss was influenced by rainfall characteristics, degree of soil aggregation and antecedent soil moisture conditions. High runoff volumes often resulted in increased soil loss while low runoff volumes gave little soil loss at the onset of the season. However later in the season soil loss tended to decrease even when runoff increased. Soil loss decreased in the order of ZT, CT, 5 FYM and 10 FYM over the experimental period. More soil was lost during the short rains 9518 gm^{-2} (ZT), 14770 gm^{-2} (CT), 10038 gm^{-2} (5 FYM) and 9346 gm^{-2} (10 FYM) than the long rains period 4478 gm^{-2} (ZT), 3974 gm^{-2} (CT), 2373 gm^{-2} (5 FYM) and 2162 gm^{-2} (10 FYM).

At low bulk density and low soil shear strength, storms of low intensity and low magnitude caused little soil loss as a result of their low erosivity. However, high intensity storms resulted in high of runoff and soil loss due to their high erosivity. Under low bulk density, soil particles were easily detached while under high bulk density and high rainfall intensity, the increased runoff led to more soil loss and runoff at the onset of the season. Later in the season after the soil had crusted and compacted due to raindrop impact, high rainfall intensities led to increased runoff but reduced soil loss.

Farmyard manure application significantly reduced soil loss through improved soil aggregation and a reduction in bulk density and soil shear strength.

Recommendations

Soil aggregation due to improved organic matter content of the soil is practically feasible in a farmer's setting only through periodic application of farmyard manure as a farm management practice .The combined effects of improved crop growth and soil conditions as a result of farmyard manure application can be expected to lead to some significant reductions in soil and water losses.

Zero tillage is recommended on medium textured soils with high biological activity and on self structuring, cracking clay soils. Zero tillage is also favourable where the top soil is shallow, stable, of high organic matter content and underlain by structurally unstable soils such as plinthite. Hence zero tillage is not appropriate for the soil conditions at Katumani. Zero tillage is not suitable for this soil because it leads to alot of runoff due to soil sealing and crusting. Furthermore the high bulk density observed under zero tillage may impede root development and subsequently lead to poor crop performance.

Conventional tillage without any farmyard manure leads to a lot of soil loss for this structurally unstable soil which has an inherent low aggregate stability. In the absence of farmyard manure and crop residues, mechanical measures such as ridging are recommended in order to conserve as much runoff as possible in situ.

Acknowledgements

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PHOSPHORUS LEACHING FROM SET-ASIDE ON CLAY SOIL

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ABSTRACT

Phosphorus leaching in drainage water and surface runoff was studied on a heavy clay soil with a mean slope of 2%. The experiment lasted four years, and consisted of set-aside treatments with four cropping sequences: 1 = fallow F, barley B, F, B; 2 = F, F, F, B; 3 = ryegrass R, B, R, B; 4 = timothy+ meadow fescue T, T, T, B. The fallows were tilled three times during the summer, and the grasses were not fertilized. Surface runoff carried 57-95% of the phosphorus losses. During the first two and a half years, particulate phosphorus (PP) concentration in surface runoff was highest in treatment 2 and lowest in treatment 4. Expressed as the sum over this period, PP leaching was 2.9, 3.2, 2.2, and 1.7 kg/ha in treatments 1,2,3, and 4, respectively. During the same period, dissolved orthophosphate (DP) leaching was 0.19, 0.21, 0.19, and 0.30 kg/ha. DP concentration in surface runoff in treatment 4 increased sharply and was much higher than in the other treatments at the outset of snowmelt and surface runoff in the second spring. After plots had been ploughed in the autumn of the third year, DP and PP concentrations in runoff from treatment 4 settled to the level of the other treatments. To minimize PP losses, set-aside fields should be under perennial unfertilized grass, undersown in the previous year to ensure a better soil cover at the beginning of the set-aside period. DP leaching may exceed that from bare fallow, but will probably remain lower than from fertilized grass.

INTRODUCTION

Set-aside fields cover 20% of the total cultivated area in Finland and are under widely different management ranging from frequently tilled bare fallow to perennial grassland. Where the area is large and the management inappropriate, leaching from set-aside fields may considerably augment the agricultural contribution to eutrophication. Bare fallow soil is more erodible than soil covered by vegetation (1,2,3). Owing to strong adsorption of phosphorus on soil constituents, particulate phosphorus (PP) losses are also higher from bare fallow (1,4). Plant and plant residue cover reduce erosion, and decrease the movement of larger soil particles in particular (5,6). Plant cover may increase leaching of dissolved phosphorus (DP), however (1,4,7,8). If the soil covered by vegetation is unfertilized, any increase in the leaching will probably be due to phosphorus leaching from plant material (1,9), especially after freezing and drying (10,11). In Finland, studies have shown DP leaching to be greater from fertilized grassland than from cereal cultivation (12,13); so far there have been no experimental studies on phosphorus leaching from unfertilized grassland, nor from fallow fields. The aim of the present experiment was to study the contributions of PP and DP to phosphorus leaching from set-aside soil. The results may be useful in establishing measures for good management of set-aside fields to minimize water pollution.

MATERIALS AND METHODS

The drainage field

The soil on the experimental field contained 43-79% clay fraction in the plough layer (0-20 cm) and was classified as silty or heavy clay according to the Finnish criteria. The clay content in the deeper layers (0-80 cm) was higher, varying between 62 and 94%. The mean slope of the field was 2%, varying between 1 and 4%. The water conductivity in the plough layer was 40-100 cm/h, and in the deeper layers (20-40 and 40-60 cm) 0.1-1.5 and 0.002-0.007 cm/h. The content of plant-available phosphorus, determined as phosphorus dissolved in acid ammonium acetate (pH 4.65), was 3.6 in the plough layer, and 0.2 in the deeper layers.

The field consisted of 16 plots, 33 m x 33 m, each with separate drainage system to allow measurement and analysis of the discharge. The ceramic drainage pipes (diameter 40 mm), two per plot, were laid parallel, 16.5 m apart, at a depth of about 1 m. At one end, the drains of each plot were connected to a plastic pipe, which carried the drainage water from each plot to an observation building where the volume was measured and a representative sample was taken from each measured lot of water. The surface water, in turn, was collected from four larger plots (each consisting of four drainage plots) into an open ditch at the lower edge of the field, and conducted via wells to the observation building.

Water analysis

The water samples were analysed for total phosphorus (TP) and dissolved ortho-phosphate phosphorus (DP). In the TP determinations, carried out on unfiltered samples, inorganic phosphate complex compounds and organic phosphorus compounds were converted into orthophosphate hy oxidizing with peroxodisulphate in acid solution. The concentration of orthophosphate was then determined by the method of Murphy and Riley (14). Before DP analysis, the water was filtered through a membrane filter (Sartorius 11306-PFN, pore size 0.45 μm), and the orthophosphate concentration was measured as described. The particulate phosphorus (PP) concentration was calculated as the difference between TP and DP. The amount of particles less than 2 μm in size was determined by pipette method. Also, the PP content of these particles was measured.

Experimental system

In spring 1987, a four-year experiment was set up to study PP and DP leaching from bare fallow and unfertilized grassland. The experiment consisted of four cropping sequences: 1 = fallow, barley, fallow, barley; 2 = fallow, fallow, fallow, barley; 3 = grass, barley, grass, barley; 4 = grass, grass, grass, barley. In sequence 3 the grass was an annual species, Italian ryegrass (*Lolium multiflorum*). In sequence 4 it was a mixture of two perennial species, timothy (*Phleum pratense*) and meadow fescue (*Festuca pratense*). The fallows were tilled three times during summer, and the grasses were not fertilized. Barley was given nitrogen, phosphorus and potassium at rates of 96, 42 and 78 kg/ha/a, respectively.

RESULTS AND DISCUSSION

Due to the very low water conductivity of the deeper soil layers, surface runoff was greater than drainage (Table 1) and carried 57-95% of the phosphorus losses. PP concentration in surface water was 1.5-2 fold the concentration in drainage water (Table 1). Expressed as the sum over two and a half years, PP leaching was 2.9, 3.2, 2.2, and 1.7 kg/ha in treatments 1,2,3, and 4, respectively. During the same period, DP leaching was 0.19, 0.21, 0.19, and 0.30 kg/ha.

Table 1. Surface runoff, drainage (mm), and particulate phosphorus (PP) and dissolved orthophosphate phosphorus (DP) concentrations (mg/l) in surface runoff and drainage water during the set-aside experiment. Set-aside management during the four years: Treatment 1 = fallow F, barley B, F, B; 2 = F, F, F, B; 3 = ryegrass R, B, R, B; 4 = timothy T, T, T, B.

	SURFACE RUNOFF			DRAINAGE		
Treatment/ Year/Crop	Water,mm	PP,mg/l	DP,mg/l	Water,mm	PP,mg/l	DP,mg/l
1 / 1 / F	270	0.39	0.022	92	0.20	0.022
2 / B	258	0.45	0.027	86	0.17	0.023
3 / F	245	0.62	0.028	71	0.41	0.042
4 / B	211	0.27	0.033	66	0.20	0.030
2 / 1 / F	154	0.38	0.026	141	0.30	0.035
2 / F	219	0.72	0.027	106	0.38	0.038
3 / F	229	0.63	0.031	117	0.51	0.043
4 / B	145	0.28	0.041	116	0.24	0.043
3 / 1 / R	247	0.32	0.024	82	0.25	0.025
2 / B	229	0.35	0.026	90	0.13	0.022
3 / R	283	0.69	0.028	53	0.43	0.038
4 / B	210	0.25	0.029	69	0.13	0.029
4 / 1 / T	263	0.30	0.034	55	0.18	0.027
2 / T	327	0.17	0.046	60	0.17	0.033
3 / T	309	0.77	0.029	38	0.37	0.053
4 / B	248	0.27	0.036	44	0.18	0.045

In the first year (June 1987 - May 1988), differences in PP concentration between the treatments were small. In the second year (June 1988 - May 1989), PP losses from continuous fallow increased dramatically, presumably due to deterioration of the surface soil structure. In the case of grass cover, by contrast, PP losses decreased during the second year hecause of the denser grass cover was able to protect soil against detachment of soil particles. Especially during the spring of the second year the grass very effectively reduced the PP concentration in surface runoff (Figure 1). After the grass plots were ploughed in October of the third year, PP concentration in surface runoff increased and stayed higher than for the other treatments until the next spring.

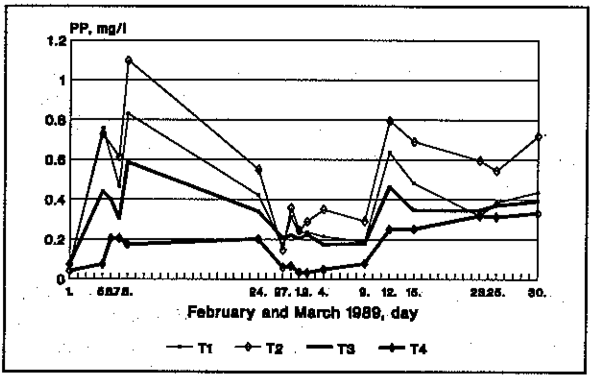

Figure 1. Particulate phosphorus (PP) concentration in surface runoff during snowmelt 1.2.- 30.3.1989 in the second experimental year. Treatments as in Table 1.

According to the measurements of the size of the eroded soil particles, 69 - 100% of PP was attached to particles smaller than 2 μm. Small clay-sized particles sedimentate slowly, allowing more time for primary production to use the attached PP (5). Particle size was slightly smaller in surface runoff from grass plots (treatment 4) during the second year, indicating higher erosivity of the smaller clay particles in that year.

In the second spring, at the outset of snowmelt, DP concentration in surface runoff increased dramatically in the grass plot (Figure 2), indicating leaching from vegetation, as reported by Timmons & Holt (10) and Ulén (11). During the second year , DP leaching from the grass plot was at the level reported by Uhlen (1). However, DP leaching from the unfertilized grass in the present experiment was low, compared with the leaching from fertilized grass observed in our earlier experiment (12,13).

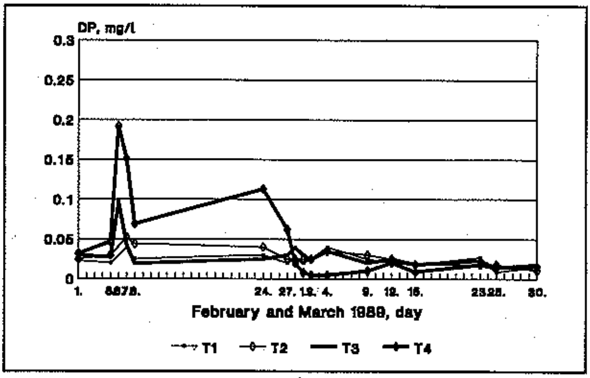

Figure 2. Dissolved orthophosphate phosphorus (DP) concentration in surface runoff during snowmelt 1.2.-30.3.1989 in the second experimental year. Treatments as in Table 1.

The increase in DP concentration in the grass plot in the second year conincided with a reduction in erosion. Following Sharpley et al. (15), this might have been due to less adsorption of plant residue phosphorus on to the fewer soil particles in the surface runoff. Now the significance of increased DP leaching depends on the bioavailability of the PP (7): if only a small proportion of the PP ever becomes available, as argued by Ekholm et al. (16), the higher DP leaching from perennial grass will partly cancel the positive effect of reduction in PP loss.

CONCLUSIONS

PP losses from set-aside soil can be minimized by establishing perennial grass cover. The grass should be undersown in the preceding year to ensure a better soil cover at the beginning of the set-aside period. Although the DP leaching may be greater from unfertilized grassland than from bare fallow, it should still be lower than from fertilized grass.

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LYSIMETER MEASUREMENTS OF NUTRIENT LOSSES FROM A SANDY SOIL UNDER CONVENTIONAL-TILL AND RIDGE-TILL IN SEMI-ARID ZIMBABWE

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ABSTRACT

Nutrient losses and percolation from the root zone were measured under a conservation tillage system (no-till tied ridging) and conventional mouldboard ploughing over a two year period. The objective was to evaluate whether decreased runoff and higher infiltration in tied ridging are causing higher nutrient losses to leaching. Six percolation lysimeters were installed in a sandy soil derived from granite. In each tillage treatment two lysimeters were under a maize crop and one under bare fallow. Rainfall and percolate volume were measured daily and analysed for nutrients.

In the first year, due to an extreme drought, no leaching occurred. In the second year approx. 25% of the seasonal rainfall drained but there were no significant differences between tillage treatments. Nutrient losses, however, were substantially lower in the ridge-till system. For the two major nutrients leached, NO_3-Nitrogen and Potassium, tied ridging reduced losses by 40% (NO_3-N) and 55% (K) under maize and by 27% (NO_3-N) and 51% (K) under bare fallow. The same trend appeared with phospate and calcium, but total amounts leached were very low. The nutrient-conserving effect of the tied ridging system was explained by the highly permeable sandy soils which provide for rapid vertical drainage of excess water in the furrows without leaching the ridge, in which the nutrient-rich topsoil is accumulated. Under these conditions, combined with its larger rooting volume, tied ridging is likely to provide a more favourable nutrient supply to plants than plough-tillage. The study also showed that under the prevailing rainfall and cropping pattern substantial drainage is likely to occur mainly early in the growing season when water uptake by plants is still low.

INTRODUCTION

Research on tillage induced soil erosion in Zimbabwe showed that a tillage system called "no-till tied ridging" (1) had the lowest soil losses and losses of water through surface runoff (2). In one experimental site (Makoholi), cumulative runoff during five years (1988-1993) amounted to 61 mm (1.7% of seasonal rainfall) under tied ridging, versus 234 mm (8.0% of seasonal rainfall) under conventional mouldboard ploughing. Cumulative soil loss amounted to 3.0 tons/ha under tied ridging, versus 20.2 tons/ha under conventional tillage (3). Effective soil and water conservation in tied ridging is due to increased water infiltration in the mechanically formed furrow-basins. Higher infiltration and minimal nutrient losses due to sheet erosion, however, can increase percolation and related leaching of available nutrients. Therefore, the major objective of this study was to quantify differences in drainage and nutrient leaching under tied ridging and conventional tillage.

MATERIALS AND METHODS

Experimental site

The study was carried out at Makoholi Research Station near Masvingo in southern Zimbabwe (1210m a.s.l.). The long-term average annual rainfall amounts to 643 mm occurring in a one-modal distribution from October to April and the average annual open pan evaporation is 1415mm (4).

The soils of the study area are coarse grained, granite-derived sandy soils classified as ferrali-gleyic and luvi-gleyic Arenosols (5,6). The coarse texture (88-93% sand, 3-8% silt, 4-6% clay) and low organic carbon contents (<0.5%) (7) induce a low water and nutrient holding capacity (AWC = 9% Vol) (6). Undulating stone lines occurring in depths of 50 to 80 cm limit the effective rooting volume for annual crops to approx. 50-70 cm depth. Rapid drainage in the rooting zone (approx. 30-40 cm/hour basic infiltration rate) aggravates the low inherent fertility through leaching of nutrients. Crop production on these soils is widespread in the smallholder farming sector in Zimbabwe.

Lysimeter design and installation

In November 1991 six percolation lysimeters (1.5m x 0.9m surface and 0.5m height, galvanised sheet metal) were installed on a 4.5% slope at a depth of 0.75m below surface, which corresponds to the maximum rooting depth. To allow for tillage and undisturbed interflow the upper margin of the lysimeters ends at 0.25m below surface. At the bottom of the lysimeters a layer (50mm) of fine gravel provides the percolate reservoir. The bottom has a slope towards the outlet, where a filter package (8) was installed and the water flows in pipes to a collection pit by gravity flow. For installation of the lysimeter boxes, the sandy soil was excavated and refilled in layers corresponding to soil horizons. To regain the natural bulk density of 1.4-1.5 Mg/m^3 slight compaction of the refilled soil was carried out.

This procedure is technically simple and cheap to implement but has disadvantages against an undisturbed soil monolith or column (9) and weighing lysimeters (10). However, (the soil being a coarse, almost structureless sand under natural condition) disturbance of the soil, if it is accurately excavated and refilled, is not expected to have a major impact on the drainage pattern (11). Hydraulic conductivity in sandy soils with low organic matter content depends greatly on soil texture (12) and the primary pore system.

Treatments

Two tillage treatments were under study, namely no-till tied ridging (1) (TR) and conventional mouldboard ploughing (CMP). Ridges, spaced 0.9m, were constructed to an unconsolidated height of 250mm with an animal drawn ridger and tied in an interval of 1.5m. The crop was planted into the crest of the ridges by digging hoe. Four to six weeks after emergence and after harvest ridges were re-ridged and re-tied as a weeding operation. Being semi-permanent, tied ridges remain unploughed for three to four years before they are built afresh. Conventional tillage was carried out annually by an animal drawn single-furrow mouldboard plough to a depth of 200-250mm. Planting and weeding was carried out by hoe.

Both tillage treatments were applied on field plots measuring 20m x 20m with three lysimeters under each treatment. The plots were subdivided into 20m x 15m and 20m x 5m subplots, the larger plots being cropped and the smaller plots being left bare. Two lysimeters were replicated under crops in each treatment (TR crop and CMP crop) whereas one lysimeter was left bare under each tillage treatment (TR bare and CMP bare). In tied ridging one lysimeter comprised the area of one furrow (basin) and two ridge-halfs.

During the initial land preparation (1991) the grass fallow was ploughed, weeds and coarse roots were removed, lime was applied at a rate of 600 kg/ha and cattle manure was applied at a rate of 7 tons/ha on the portion to be cropped. Maize (*Zea mays L.*) was grown in both years at a density of 36000 plants (spaced 0.9m x 0.31m) and fertilised with compound fertilizer before planting (8% N, 14% P, 7% K, 6.5% S) at a rate of 200 kg/ha and top-dressed after six weeks with ammonium nitrate (34.5% N) at a rate of 100 kg/ha. No fertilization was carried out on bare treatments.

Measurements

Rainfall and percolate volume were measured daily over a two year period (1991/92 and 1992/93). The percolate was then analysed for nutrients, and pH and electrical conductivity were determined by pH-meter and conductivity meter respectively. Colorimetric determination (13) of nitrate, potassium, phosphate calcium and magnesium was carried out by spectrophotometer after calibration with standard solutions. Nutrient concentrations were determined and multiplied with the percolate volume to obtain absolute losses which were calculated as kg/ha.

RESULTS AND DISCUSSION

Percolate, pH and electrical conductivity

The most severe drought in a century during the 1991-92 season (173mm rainfall) resulted in a complete crop failure and no percolation beyond 0.7m depth occurred. In the second season (Oct. 1992 - April 1993) rainfall was 709mm and maize yield was 4.7 tons/ha on TR and 4.1 tons/ha on CMP. First drainage occurred after a storm of 58mm at the end of November (Fig.1). During only 9 days (December 19-27), 53% of total seasonal drainage under crops occurred. By January 5, 91% of total drainage had already occurred on the cropped treatments. Despite high rainfall in February (243mm) minimal drainage losses occurred after crop development had reached the tasselling stage in early January. The high water consumption of maize plants was evident from high percolation volumes in the bare treatments in February (ave. of 114mm more on bare, see Fig.1 and Table 1). Differences in the percolate volumes between tillage treatments were minimal and not significant ($P<0.05$), but were distinct between bare and cropped treatments. Under crops, deep percolation into the ground water was approx. 25% of the seasonal rainfall in both, TR and CMP.

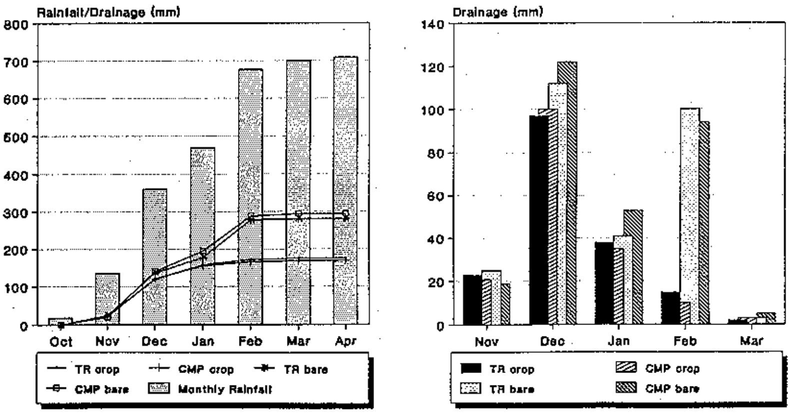

Figure 1: Cumulative rainfall and drainage from lysimeters (left) and monthly drainage from lysimeters (right) in the 92/93 rainy season.

Average pH of the percolate for all treatments was 7.18. Treatment differences were negligible. Electrical conductivity of the percolate reached up to 0.8mS/cm under CMP (0.5mS/cm in TR) at the beginning of the season and dropped to approx. 0.2mS/cm in all treatments by February. These values indicate generally low contents of soluble salts (12). On average, electrical conductivity was 38% lower on TR crop than on CMP crop and 27% lower on TR bare than on CMP bare.

Nutrient losses to leaching

Only nitrogen and potassium showed relevant nutrients losses. Losses of other nutrients were very low (Table 1) and thus irrelevant.

Table 1: Total seasonal percolation and nutrient losses from the root zone (0.7m) subject to two different tillage treatments, (TR and CMP) under maize and under bare soil in the 1992/1993 growing season.

Tillage Treatments	Percol mm	NO_3 conc[2] mg/l	NO_3 kg/ha	K conc[2] mg/l	K kg/ha	PO_4 kg/ha	Ca kg/ha	Mg kg/ha
TR crop[1]	176	15.35	31.1	4.2	8.3	0.028	0.40	0.33
CMP crop[1]	170	25.00	51.9	9.9	18.4	0.029	1.03	0.20
Diff (TR/CMP)	+4%	-40%	-40%	-58%	-55%	-2%	-62%	+65%
TR bare	281	21.9	66.4	6.3	18.2	0.027	0.62	0.58
CMP bare	293	26.4	91.2	11.9	37.4	0.068	1.11	0.65
Diff (TR/CMP)	-4%	-17%	-27%	-47%	-51%	-61%	-45%	-10%
Till.eff. sign[3].:	n.s.	*	n.s.[4]	*	n.s.	n.s.	***	n.s.

[1] ave. of two replicates.; [2] seas. ave.; [3] sign. levels: *=5%, **=1%, ***=0.1%
[4] sign. at * in cropped treatments

Nitrate

High percolation caused the highest Nitrate losses from all treatments in December 1992 (Fig.2). In only 9 days (see above) 64% of the total NO_3-N loss was recorded in CMP crop and 61% in TR crop. In the bare treatments losses were 54% in CMP bare and 45% in TR bare. This period coincided with topdressing. However, looking at the even higher N-losses in the unfertilised bare treatments and at the nitrate concentrations in the percolate, it can not be concluded that the main source of the N-loss was fertilizer. High N-mineralization before this rainy period, in particular on bare treatments (due to higher soil temperatures) and subsequent "flushing" of mineralized N are likely to be the main source. As from January 1993 high N-uptake resulted in minimal N-losses in the cropped treatments as opposed to the bare treatments (Fig.2). Total seasonal NO_3-N losses in kg/ha were 40% less on TR crop compared to CMP crop and 27% less on TR bare than on CMP bare. This trend was also reflected in the nitrate concentration of the soil solution, which confirms the effect of the tillage treatment (Table 1).

Extremely high N-losses in the bare treatments and also in CMP crop (Table 1), where losses were higher than the applied nitrogen amount of 50.5 kg/ha N, confirm high N-mineralization processes. Likely factors which caused intensive mineralization are abundant fine roots from the grass fallow under which the field plots were before they were taken under cultivation in November 1991 and the disturbance of the soil during lysimeter installation. Similar effects are mentioned in (14). In this case, high nitrate losses on bare treatments are expected to drop during the following years.

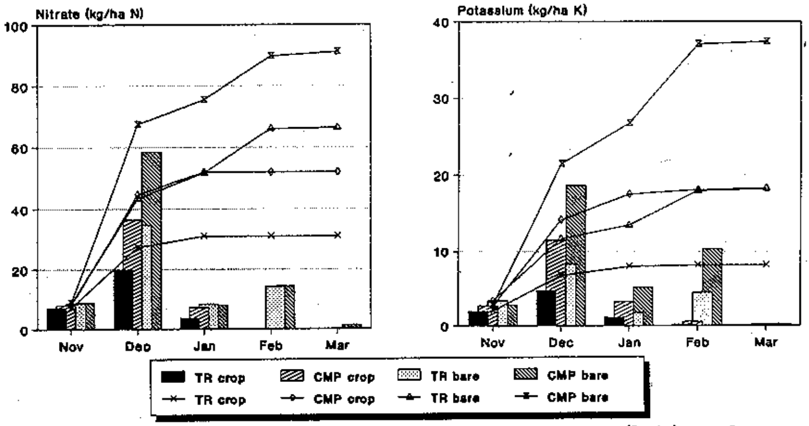

Figure 2: Monthly and cumulative leaching of nitrate (left) and potassium (right) from Lysimeters in the 92/93 rainy season.

Potassium

The same trends and patterns as found with nitrogen in the tillage effect on leaching showed with potassium. On TR crop 55% less potassium was leached than on CMP crop. Bare treatments provided similar figures with 51% less K-losses on tied ridging (Table 1). Total K-losses are high in all treatments except TR crop. Application of 14 kg/ha K, high mineralization and high mobility of K due to low cation exchange capacity of the mainly kaolinitic clays and a very low clay and organic carbon content are the factors which account for the losses.

Phosphorus, calcium and magnesium

Leaching of phosphate, calcium and magnesium was very low (Table 1) and negligible compared to the applications (28 kg/ha P, 600 kg/ha lime). This indicates that phosphates as well as Ca and Mg are strongly bound to particles and are only minimally transported in solution but could be transported through sheet erosion on the soil surface. Nevertheless, the trend of less leaching under tied ridging showed again for phosphorus and for calcium. For magnesium, the contrary is indicated: 65% more was leached under TR crop. This could indicate that magnesium is more abundant in the subsoil where vertical transportation could be facilitated by concentrated percolation in the furrow.

Lower nutrient losses under tied ridging than on conventional tillage are caused by rapid vertical drainage in the furrow-basins, while the nutrient-rich and fertilised topsoil is protected in the ridge and remains "unflushed". This applies to well drained sandy soils only. In a different climate and/or soil type, different processes may lead to opposite results as indicated from a complementary study in northern Zimbabwe, where leaching was higher under TR (15). The study will continue for another three seasons and complementary flux calculations will be able to provide further evidence of the findings. The simple methodology utilzed appears appropriate and satisfactory for the set objectives.

CONCLUSIONS

Results of only one year in which percolation occurred should be considered preliminary. Total drainage, nutrient losses and nutrient concentrations in the soil solution, however, indicate a clear tillage treatment effect on nutrient leaching from the root zone. Tied ridging in this study was able to protect nutrients more effectively from leaching and, combined with protection of soil and nutrients from sheet erosion one would expect a higher nutrient supply to plants under this treatment. Yields obtained and farmers who are presently testing this tillage system confirm this hypothesis, but data from more years and consideration of other factors such as higher early-season soil temperatures and soil evaporation under tied ridging are required. Trends of the present 1993/1994 season are confirmative so far.

The study also shows that despite semi-arid conditions, up to 25% of the seasonal rainfall can percolate in the sandy soils and recharge the groundwater. Substantial amounts of drainage and nutrient leaching from cropped fields occur mainly early in the growing season. As from tasselling stage (maize) water uptake by plants is high and can limit drainage to a minimum even under wet conditions in February. Regarding the nitrogen flush in December, when high rainfall is expected, early planting appears to be a major measure for optimising nutrient and water use by plants.

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INFLUENCE OF TILLAGE, N SOURCE AND METHOD OF N PLACEMENT ON THE RECOVERY OF ^{15}N-LABELLED FERTILIZERS

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ABSTRACT

Field experiments were conducted at Rimbey and Innisfail in central Alberta to determine the influence of tillage, N source and method of N placement on the recovery of ^{15}N-labelled fertilizers in barley plants and in soil. The first experiment compared four broadcast N sources (urea, ammonium sulphate (A.S.), ammonium nitrate (A.N.) and KNO_3). With the exception of KNO_3 , the N recovery in barley plants was lower under ZT than CT. The plant N recovery under ZT was urea <A.S. <A.N. <KNO_3. Immobilized N in soil was often less with KNO_3 than the other N sources. In the second experiment, methods of placement were evaluated. The recovery of N in plants was lowest for surface-broadcast urea under ZT and banding urea beside and/or below the seedrow increased N recovery in plants markedly. Method of placement had little effect on N immobilization under ZT, but under CT the amount of immobilized N was less with subsurface banding than incorporation. Simulated rainfall immediately after urea application under ZT increased the N recovery in plants.

INTRODUCTION

Zero tillage (ZT) is one of the most effective methods in conserving soil and water, and has less requirements for labour, fuel and machinery than conventional tillage (CT). However, ZT may reduce crop utilization of fertilizer N (4), and increase potential for immobilization (7), dentrification (1) and leaching (5) of mineral N. The difference in the availability of fertilizer N to plants under ZT versus CT depends on N source and method of placement. In U.S.A., urea-containing fertilizers have been found less efficient than non-urea fertilizers under ZT (2, 9, 16). There is no published information available on the efficiency of urea compared to other N sources for ZT in central Alberta.

On ZT, the most common method of N application is broadcast on the soil surface. Urea is the most dominant dry N fertilizer, but surface-applied urea is subject to substantial N loss through ammonia volatilization (17). Placement of N fertilizer in bands below the soil surface can prevent N loss through ammonia volatilization (3) and improve the availability of fertilizer N to plants under ZT (2, 11, 16).

In central Alberta, barley yields are generally lower under ZT than CT when N fertilizer is broadcast on soil surface (13), and band placement of urea reduced or eliminated yield differences between ZT and CT (10, 12). Since ^{15}N-labelled fertilizers were not used in those experiments, it was not possible to determine the recovery of N by plants and by soil. The objective of this study was to determine the effect of N source and method of placement on the recovery of ^{15}N-labelled fertilizers applied to barley in plants and in soil.

MATERIALS AND METHODS

The study was conducted at Rimbey (north-central Alberta) and Innisfail (central Alberta) in 1989. The soil at Rimbey was Gray Luvisol (Boralf) with 7.0 pH, 31 g/kg organic matter and a loam texture. At Innisfail, the soil was Black Chernozem (Udic Boroll) with a pH of 7.0, organic matter 65 g/kg and a loam texture. The mean annual precipitation of the area is about 450 mm. The two experiments were established in spring, 1989 within large plots which had been under zero tillage (ZT) and conventional tillage (CT) for 5 or 6 years before. Each treatment was contained in a 45 cm long x 45 cm wide x 18 cm high bottomless steel frame set 13 cm deep in the soil. In all experiments, each treatment was replicated four times in a split-plot design with tillages in main plots and N sources in subplots. The atom % ^{15}N abundance of the labelled fertilizers was about 5%. The test crop was barley (*Hordeum vulgare* L. cv. Galt). Barley was sown about mid May and there were two 22.5 cm apart rows per frame.

Experiment 1. Source of N Application

There were two tillage treatments (ZT and CT) and four sources of N (urea, ammonium sulphate (A.S.), ammonium nitrate (A.N.) and potassium nitrate (KNO_3)). The rate of N was 50 kg N/ha. The N fertilizers were broadcast on soil surface for ZT, while in CT plots they were incorporated into the top 10 cm by hand just prior to sowing of barley.

Experiment 2. Method of N Application and Simulated Rainfall

The treatments were: surface-broadcast, simulated rainfall, ZT; surface-broadcast, ZT; side band, ZT; deep band, ZT; broadcast and incorporated, simulated rainfall, CT; broadcast and incorporated, CT; and side band, CT; and deep band, CT. The N source was urea applied at 50 kg N ha^{-1}. Surface-broadcast under ZT and incorporation under CT were same as in Experiment 1. In the "side banding" method urea was applied about 4 cm beside and 4 cm below the seedrow, while in the "deep banding" application the N fertilizer was placed about 4 cm directly below the seedrow. In the "simulated rainfall" (SR) treatments, urea was applied two days before sowing. The "SR" treatments received 10 mm of water sprinkled over the microplots after urea application.

In both experiments, barley was harvested by cutting mature plants at the ground level. The plant samples were subdivided into heads and straw. In each plot, roots were collected by digging out the 0-15 cm soil and washed to remove adhering soil. The plant and root samples were dried at 65°C and ground to pass a 1-mm sieve for ^{15}N analysis in total N. After harvesting, each plot was soil sampled to a depth of 0-15, 15-30, 30-60 and 60-90 cm. After drying soil at room temperature, the samples were ground through a 0.5-mm sieve for ^{15}N analysis in total N. The data were subjected to analysis of variance.

RESULTS AND DISCUSSION

Experiment 1. Source of N Application

With the exception of KNO_3, the N recovery in barley plants (heads plus straw plus roots) was lower under ZT than CT (Fig. 1). The plant N recovery under ZT was least for urea, followed by A.S. and A.N. and with the highest for KNO_3 at both sites. Even under CT, KNO_3 had the greatest plant N recovery and A.N. gave higher N recovery than urea though the differences between A.N. and urea were smaller than under ZT. There was generally less soil N recovery (immobilized N) with KNO_3 than the other N sources.

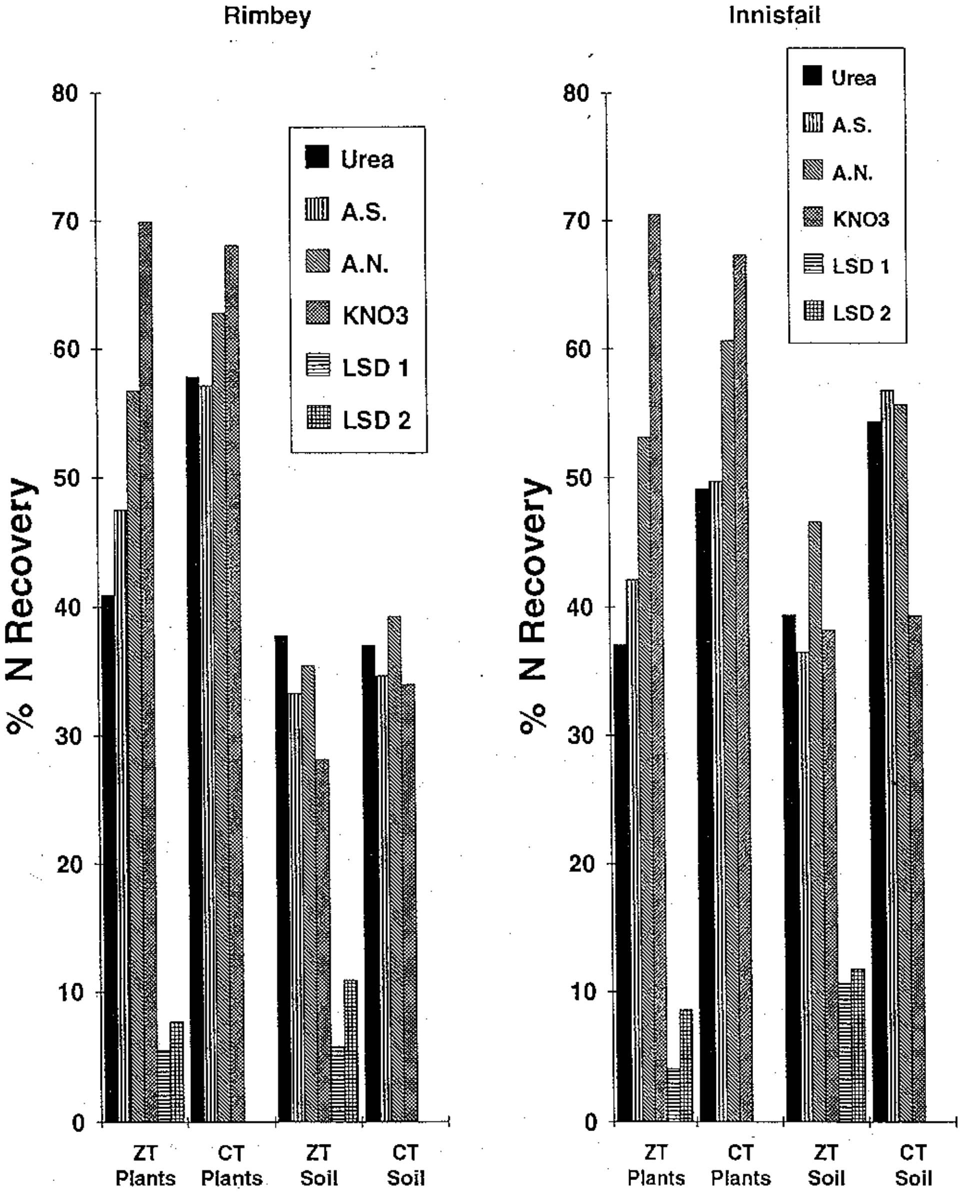

Fig. 1. Influence of tillage and N source on the recovery of ^{15}N-labelled fertilizers in barley plants and soil in a field experiment at two locations in central Alberta (Experiment 1). LSD 1 is to compare N sources for the same tillage and LSD 2 is to compare tillages for the same N source or to compare N sources at different tillages.

Researchers (8, 17) have reported that when ammonium-based fertilizers, particularly urea, are left on the soil surface, substantial N loss can occur by ammonia volatilization and thus leaving less N for plant uptake. The lowest ^{15}N recovery in plants and plants plus soil from surface-applied urea under ZT than the other N sources in the present study was most likely due to ammonia volatilization. Similarly, in other research (2, 16), urea has been found less efficient than non-urea fertilizers when not incorporated into the soil. The greater plant ^{15}N recovery from KNO_3, or A.N., than urea or A.S. in the present experiment was probably because of faster downward movement through soil profile and subsequently more accessibility of applied N to plant roots. The increased ^{15}N recovery in barley plants by incorporation of urea into the soil was presumably because of decreased ammonia volatilization (15).

Experiment 2. Method of N Application and Simulated Rainfall

The ^{15}N recovery in barley plants with broadcast application was considerably lower under ZT than CT, but with subsurface banding the differences in the N recovery between ZT and CT were much smaller (Fig. 2). This indicated that surface-applied urea N under ZT became less available to plants compared to incorporated urea under CT, because of its position away from the roots and also possibly due to substantial N loss through ammonia volatilization. McInness et al. (14) reported that when urea is applied to surface soil under ZT, the high urease levels in the straw residues can result in large ammonia volatilization loss. This explains why crop yields in the previous field experiments in central Alberta with commercial urea were lower under ZT and CT with broadcast application (12, 13).

Banding urea beside and/or below the seedrow in comparison to broadcast application increased the ^{15}N recovery in plants markedly, particularly under ZT. This suggested that placement of N fertilizer in bands below the soil surface can minimize ammonia volatilization (3, 6) and improve the availability of fertilizer N to plants (2, 16). This also explains why barley yields under ZT improved when commercial urea was banded at time of sowing in other Alberta experiments (10, 12).

The amount of ^{15}N left in soil with broadcast application was greater under CT than ZT. This is because some N from surface-applied urea under ZT was lost from the soil system by ammonia volatilization and thus, leaving less N in soil for immobilization. Also, with incorporation under CT, because of greater interaction of the fertilizer N with soil more N became accessible to microorganisms and this may have resulted in greater immobilization of applied N than ZT. The amount of immobilized N was less with banding than broadcasting but only under CT. This was because band placement minimized contact between the labelled urea N and the soil microorganisms. Also, with banding applied N was closer to plant roots which resulted in more uptake of fertilizer N and left less N in soil for immobilization by microorganisms. Other researchers (4) have made similar findings.

Simulated rainfall immediately after broadcast urea application increased the plant N recovery under ZT, especially at Innisfail (Fig. 2). However, under CT there was no effect of simulated rainfall on the plant N recovery from urea incorporation. Amount of ammonia lost from surface-applied urea depends on many factors including the amount and length of time of rainfall following application (15). If rainfall occurs shortly after N application, dissolution and downward movement of urea greatly lessens the likelihood of ammonia loss. Bauwmeester et al. (3) found no ammonia volatilization with 25 mm of rain immediately after urea application, thus leaving more N in soil for plant uptake. In the present study, the increase in ^{15}N recovery in plants with simulated rainfall added immediately after surface urea application under ZT was most likely by reduction of ammonia volatilization.

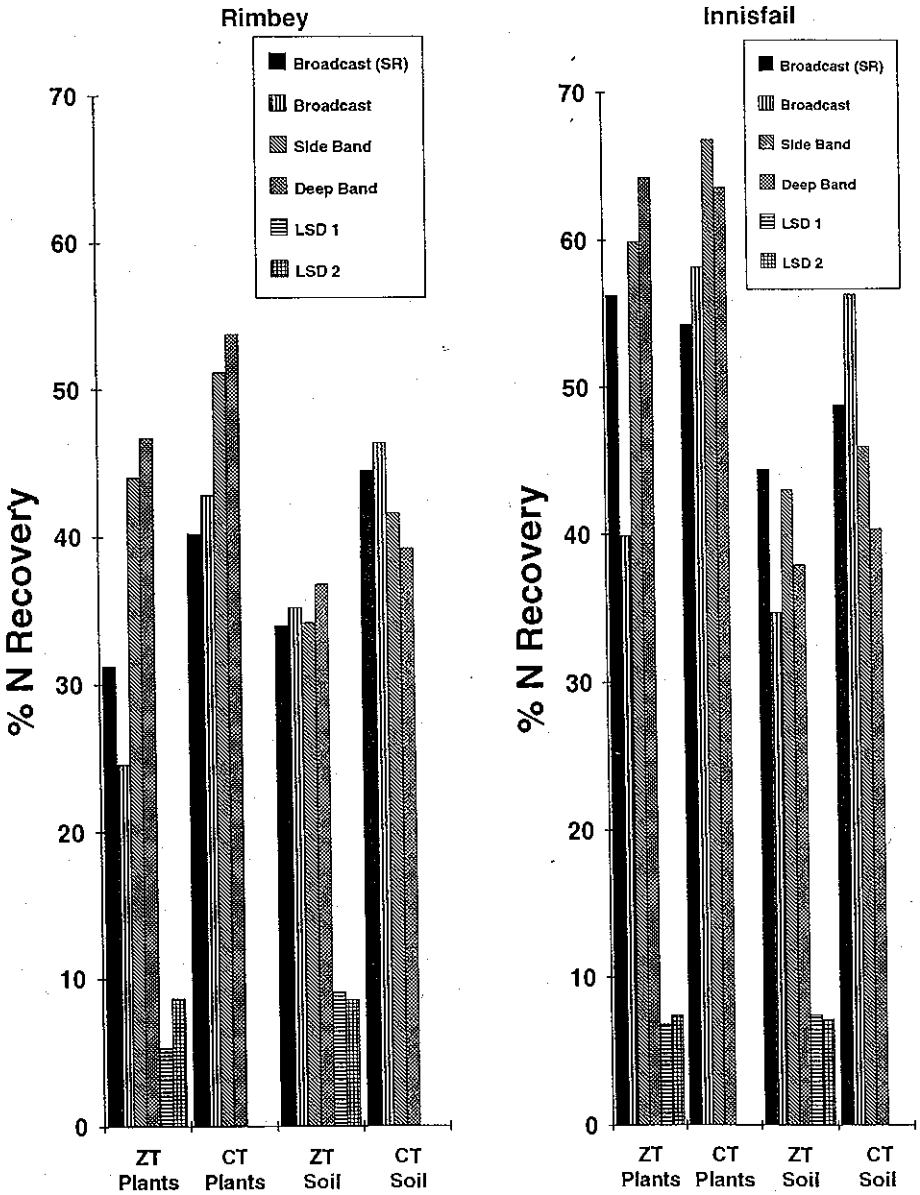

Fig. 2. Influence of tillage and method of placement on the recovery of ^{15}N-labelled urea in barley plants and soil in a field experiment at two locations in central Alberta (Experiment 2). LSD 1 is to compare placement methods for the same tillage and LSD 2 is to compare tillages for the same placement method or to compare placement methods at different tillages.

CONCLUSIONS

Urea when surface-broadcast under ZT was much less efficient than the other N sources, and KNO_3 was the most efficient. The efficiency of urea was improved considerably when it was placed in bands below the soil surface near the seedrow or when simulated rainfall was added immediately after surface-application of urea.

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THE INFLUENCE OF FROST HARDINESS AND NITROGEN-FERTILIZATION OF CATCH-CROPS ON N-CONSERVATION AND NITRATE LEACHING ON SANDY SOILS

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ABSTRACT

On two locations in the north-eastern plains of Germany the influence of resistance to frost and the amount of N-fertilization of catch-crops were investigated on their ability to conserve nitrogen. The results show that short after dying of the catch-crops caused by frost at the beginning of winter up to 60 percent of the stored nitrogen in biomass can be released until mid of January. Catch-crops surviving frost did nót show such effect.

INTRODUCTION

The growing of catch-crops is a well known possibility to reduce higher amounts of nitrate in soil after harvesting of the main crops and to reduce nitrate leaching (1,2). Especially under conditions of sandy soils with a low holding capacity for water and nitrate this measure can be of great importance (3).
The ability of catch-crops to take up free nitrogen from the soil in the time from harvesting to the beginning of winter and to store this nitrogen in the plant biomass until the following growing period is known as the so called ability of Nitrogen-conservation (4).
Most published results are dealing with the ability of the catch-crops to take up free nitrogen. The conditions of N-release during winter caused by dying catch-crops as well as the impact of N-fertilization to catch-crops are rarely examined.
The target of this work is to determine the influence of frost hardiness of catch-crops and a N-fertilization to their ability of N-conservation and nitrate leaching during winter.

MATERIALS AND METHODS

In the years of 1989-92 the experiments were conducted on fields with two typical sandy soils without groundwater influence. In the state of Brandenburg in the north-eastern plains of Germany a sandy soil in Müncheberg, district of Strausberg, and a sandy loam in Berge, district of Nauen, had been used.

The following catch-crops, selected on their hardiness to frost, had been tested:

(1) not resistent to frost:
- oilradish (oir)
- phazelia (ph)
- yellow mustard (ym)

(2) resistent to frost:
- summer rape, not dying in 1989/90 (sra)
- winter rape (wra)
- "Winterrübsen" (wrü).

The amount of N-fertilizer used in the experiments were 0/ 40/ 50/ 80/ 120 kg N/ha.

The amount of stored nitrogen in roots and shoots of plants, the C:N-ratio of plant biomass and the content of mineral nitrogen in the soil in layers of 0-30 cm, 30-60 cm and 60-90 cm depths were investigated at several times. Usually the measurements were conducted after harvest, at the beginning of winter before dying, during winter at non-frost conditions and at the beginning of the growing period.

RESULTS

1. N-uptake by catch-crops and N-reduction of mineral nitrogen in soil before winter

All tested catch-crops were able to reduce the content of mineral nitrogen in the soil below 35 kg N/ha until the beginning of winter in all levels of N-fertilization without significant differences. These low nitrate conditions in the soil at the beginning of the period of refilling of groundwater correspond to the recommended level for nitrate in soil at the ending of the growing period in the state of Brandenburg for water catchment areas (5). The N-uptake respectively the amount of nitrogen in plant biomass were significantly influenced by the N-fertilization of the catch-crops. Higher levels of N-nutrition caused higher yields of drymatter and higher amounts of N-uptake (figure 1).

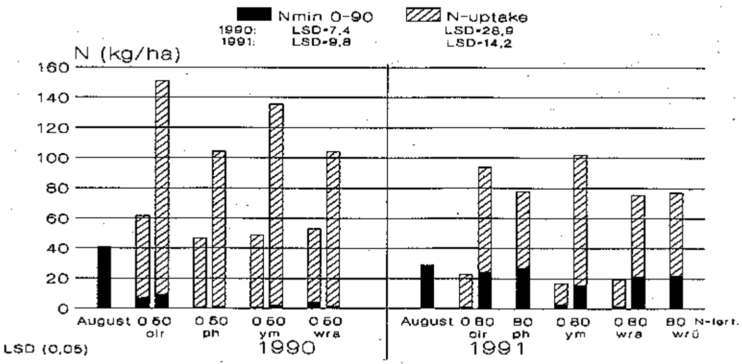

Fig. 1: N-uptake of catch-crops und reduction of mineral nitrogen in soil from harvest of the previous main crop to the beginning of winter, Müncheberg 1990 und 1991

In Müncheberg 1990 oilradish and yellow mustard took up about 135 kg N/ha under favourable growing conditions and after N-fertilization with 50 kg N/ha. Compared with the results in 1991 after fertilization of 80 kg N/ha the highest N-uptake could be observed with yellow mustard but with a total amount of only 80 kg N/ha. The reason was a very dry sommer and autumn with a strong deficit of water and a very short growing period caused by deep temperatures in the mid of October, This caused only a low biomass production.

Phazelia and the frostresistant catch-crops winterrape and "Winterrübsen" showed after N-fertilization a significant lower N-amount in their biomass than oilradish and yellow mustard. When not applying N-fertilizer to the catch-crops these differences could not be measured.

2. Dynamic of stored nitrogen in plant and of mineral nitrogen in soil from the ending to the beginning of the growing period

During winter strong differences were investigated in the stored nitrogen in biomass and in the content of mineral nitrogen in soil.

The catch-crops not resistant to frost, especially yellow mustard and oilradish, but also phazelia released a lot of the before winter stored amount of nitrogen short after their complete dying and under mild weather conditions with high soil moisture (figure 2).

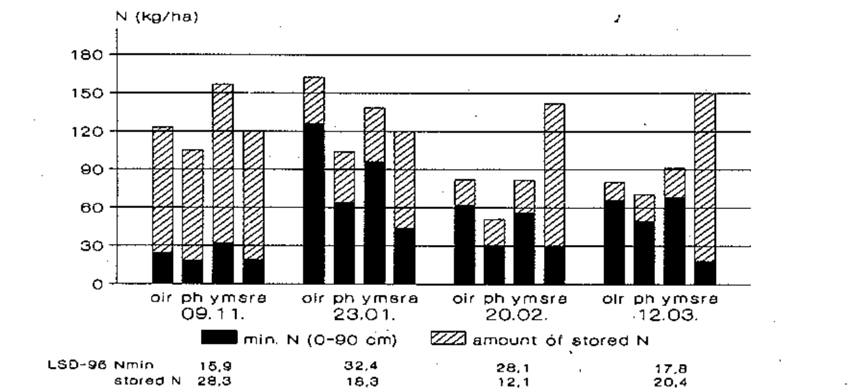

Fig. 2: Amount of stored nitrogen in catch-crop biomass and the content of mineral nitrogen in the soil during winter, Müncheberg 1989/90

Until January the amount of nitrogen released from plant biomass could be measured in soil as mineral nitrogen. Especially in the upper soil layer in 0-30 cm depth the content of mineral nitrogen strongly increased. This corresponds to the deficit of nitrogen in the upper biomass. During winter the released nitrogen had been transported into deeper soil layers (figure 3).

Especially under yellow mustard a major part of the peak in the content of mineral nitrogen in the upper soil layer with about 60 kg/ha in January has been transported within a short time of about 25 days into the 30-60 cm layer and until the mid of March into the 60-90 cm layer.

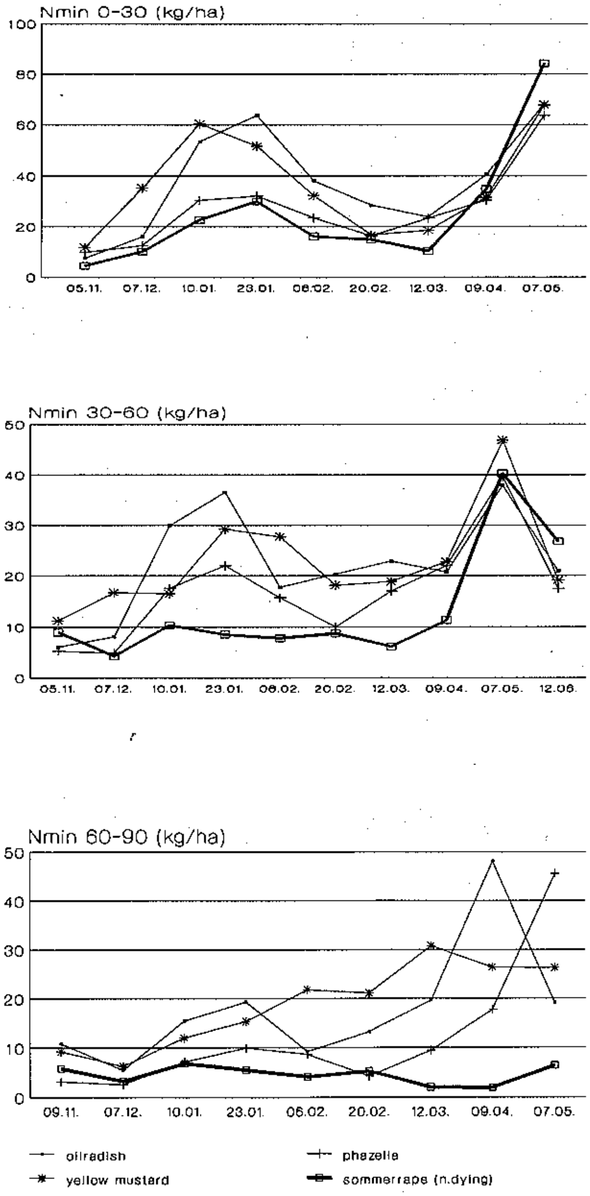

Fig. 3: Dynamic of mineral nitrogen in three soil layers under catch-crops depending on frost hardiness of the catch-crops, Müncheberg 1989/90

High levels of N-release from catch-crops after dying caused by frost were improved by increasing amounts of N-fertilizers. The different N-fertilization caused a modified rate of N-release. A fertilization of 80 kg N/ha to yellow mustard lead to a release of nitrogen of 55 percent of the N stored before winter in biomass until mid of January. Without N-fertilization only 12 percent were released during the same period. The reason could be seen in the different composition of plant material before dying (table 1). In all cases higher amounts of N-fertlizer caused an increased N-content and a decreased C:N-ratio.

Table 1: Released nitrogen and compostion of plant material of yellow mustard depending on the amount of N-fertilizer, given to catch-crops; Berge 1991/92

	amount of N-fertilizer (kg/ha)			
	0	40	80	120
released amount of nitrogen between dying in November and mid of January (%)	12,0	30,6	54,9	59,2
total released amount of nitrogen until the beginning of growing period (%)	78,0	70,1	81,8	90,0
composition of biomass before the beginning of winter				
N-content (%)	1,29	1,48	2,01	2,43
C:N-ratio	34,7	30,1	22,1	16,2

Compared to these results catch-crops not dying during winter did not cause such effects of increased N-release and -leaching during winter. Significant differences for the content of mineral nitrogen in the soil layers 30-60 cm and 60-90 cm depth during winter could not be observed. Only in the upper soil layer (0-30 cm) a small increase immediately after the first strong frost could be found. The dying of some leaves at the bottom of the plant and the subsequent N-releasing from dead biomass caused this effect. But when growing under favourable weather conditions during winter the released nitrogen was taken up again by the plants (figure 2,3; rape).

DISCUSSION AND CONCLUSIONS

The results prove on one hand the importance of catch-crops for minimizing the content of mineral nitrogen in the soil resulting from former main crops and from mineralisation in autumn until the beginning of refilling of groundwater. On the other hand they show the influence of frost hardiness respectively the dying of plant biomass caused by frost and of the amount of N-fertilizer applicated to catch-crops on their ability to conserve nitrate.

Catch-crops dying with the first frost at the end of November can release up to 90 percent of the nitrogen stored before winter until the beginning of the following period in spring. The major part usually releases within a short time after dying. The released nitrogen caused an increased content of mineral nitrogen in the upper soil layer in a short time after dying and a subsequent leaching of nitrogen in form of nitrate into deeper soil layers. Increasing amounts of N-fertilizer to the catch-crops caused a modified composition of plant biomass and a higher release intensity of stored nitrogen within a short period after dying.

Catch-crops sensitive to frost are not able to secure low levels of nitrate in the soil solution during winter. Especially varieties that dy already after only light frost and which are able to take up high amounts of nitrogen during autumn with a resulting low C:N-ratio of

their biomass can not be to prefered to fulfil the task of N-conservation and thus groundwaterprotection against contamination with nitrate.
Especially under conditions of sandy soils with a low water holding capacity and long distances of watertransport during winter as could be found in the north-eastern plains of Germany catch-crops like yellow mustard should not be used in areas that are used mainly to collect groundwater. Minimized N-fertilization or not fertilizing the catch-crops that will dy at the beginning of winter should be the goal. A better composition of biomass and a lower release intensity will be caused.

It is better to grow not dying catch-crops in such areas. They secure very low contents of mineral nitrogen in soil especially in the deeper soil layers during the period of groundwater refilling. Higher amounts of N-fertilizer cause a modified composition of plantmaterial too, but through the growing activity during winter stronger release is not possible.

Although not dying catch-crops seem to be one of the best possibilities to prevent intensive leaching of nitrate during winter some other aspects connecting with the growing of catch-crops will be investigated and should be thought over in future:

(1) the ability to grow catch-crops under the special conditions of a very dry period between late summer and autumn and the low waterholding capacity of sandy soils,

(2) the consumption of water to produce catch-crop biomass and the possibly caused deficit in groundwater refilling, especially under conditions of areas with a low precipitation and

(3) the controlling of N-release from the biomass of not dying catch-crops in the next season and the share of nutrition for the following main crop.

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EFFECT OF TILLAGE AND CROPPING SYSTEMS ON NO_3-N, WSP AND WSOC UNDER BARLEY PRODUCTION

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ABSTRACT

Nitrate (NO_3) and soluble phosphorus (WSP) from agricultural sources are often pointed as responsible for the reduction in water quality in several cultivated areas of Canada. Studies have also shown that water soluble organic carbon (WSOC) is involved in the movement of soil and water contaminants. The objective of this research was to study the impacts of cropping sequences: continuous barley (CC), barley underseeded with red clover and timothy (UB) and a combination of red clover and timothy (F_1 and F_2); primary tillage: chisel (RT) and moldboard plow (CT); and fertilizer sources: mineral (M) and dairy liquid manure (DLM) on the migration of NO_3, WSP and WSOC within a clay soil profile (clayed, mixed, frigid, Typic Humaquept). Soil samples were collected from the 0-15, 15-30, 30-60 and 60-90cm depths at -15 (prior to), 15, 45, 75, 105, 135 and 165 days after seeding during three growing seasons. Soluble NO_3-N, WSOC and WSP were obtained by analysing soil:water extracts 1:1. Distribution of the precipitations varied drastically during the three growing seasons and influenced yields of barley, establishment of red clover and timothy as well as the quantities and distribution of residual NO_3-N, WSP and WSOC in the soil profile. The CT-M system gave the highest average yield for barley whereas RT-DLM combinations led to the lowest yields. Cropping sequence was the dominant single factor among those tested on the migration of these forms of N,P,C. Fall residual NO_3-N was larger under M than under DLM fertilization with CC. Tillage practices such as those used, had limited influence on the WSOC content and maxima were generally obtained in the 0-15cm layer under DLM. Numerous significant interactions between parameters were found, suggesting the importance of multifactorial studies for an adequate selection of an environmentally optimal system.

INTRODUCTION

Nitrate (NO_3) and soluble P (WSP) from agricultural sources are held responsible for the deterioration of water quality in several areas in North America (1,2). Selection of plant species may play an important role in the removal of residual N in the soil profile.Fall and spring leaching under perennial crops is usually less important than under annual crops (3,4). The use of best management practices (BMP) and conservation tillage which are efficient in limiting surface erosion, do not always contribute to reduce significantly the amounts of nutrients that are lost by drainage and runoff waters (5).

Several studies (6,7) have reported that water soluble organic carbon (WSOC) could enhance the transport of a variety of inorganic and organic contaminants through soil profiles.WSOC would also be involved in nutrient availability (8). A 50 year application of organic fertilizers resulted in larger WSOC contents than mineral fertilizers; crop rotations had little effect (9). Despite potential implications in water quality, few studies have looked at the combined effects of components of cropping systems on WSOC, NO_3 and WSP. The objective of this research is to investigate the effect of cropping sequences, tillage practices and fertilizer sources on the contents of these constituents in a clay soil profile over three growing seasons.

MATERIALS AND METHODS

The study was initiated in the fall of 1989 on a Normandin clay (fine, mixed, frigid, Typic Humaquept) at the Normandin Agriculture Canada Research Farm, (Québec), Canada (48º50' 15"N, 73°33'12"E). The soil presented the following characteristics: pH 5,6; organic matter content 53,8g kg^{-1}, 49% of clay and 8% sand. Soils are frozen from November to early May. Rainfall distribution data were available from a weather station located less than 1km from the experimental site and the potential evapotranspiration (PET) was derived from the Penman equation. Prior to the beginning of the experiment, the site was under alfalfa (Medicago sativa L.) which was incorporated by primary tillage following herbicide treatment in October 1989. A split-split plot design was used in this study. The main plots included three cropping treatments: continuous barley (Hordeum vulgare L. cv. Chapais, CC) seeded at a rate of 170kg ha^{-1}, was compared to a 3-year crop rotation. The latter included barley underseeded (UB) with red clover (Trifolium pratense L. cv. Prosper) and timothy (Phleum pratense L. cv. Champ) mixture year 1, followed by forages, years 2 and 3. In addition, a mixture of timothy and red clover was seeded without cover crop (F_1 and F_2). In both cases (UB and F_1), timothy and red clover were seeded at the rate of 7kg ha^{-1} ; barley seeding rate was reduced by 25% in the rotation treatment, to improve timothy and clover establishment. Each crop sequence of the rotation was present every year. The subplot size was $50m^2$ and each treatment was replicated four times. Harvest of barley was performed at 105 days after seeding; straw was removed from the field.

The subplot treatments consisted of two types of primary tillage: reduced tillage (RT) with a chisel plow to a depth of 15cm and conventional tillage (CT) with a moldboard plow to a depth of 20cm. These operations were performed at about 150 days after seeding. The sub-subplot treatments referred to the fertilizer sources: mineral (M) and organic (dairy liquid manure, DLM). Mineral fertilizers were applied according to the recommendation grids used in the area whereas dairy liquid manure was applied on an equivalent N rate basis ($51m^3$ ha^{-1}). Fertilizers were incorporated to a 7.5cm depth by disk-harrow, two days prior seeding.

Soil samples were collected 6 times in 1990 and 1992 and 7 times in 1991 from the 0-15cm, 15-30cm, 30-60cm and 60-90cm layers using a 7cm diameter auger. Samples were kept at 3°C during transportation and frozen until analyses were performed. The NO_3-N, WSP and WSOC were extracted by gently shaking 20g of soil with 20ml of water for 15min in stoppered 50ml polyethylene centrifuge tubes, followed by centrifugation at 27 000g and filtration through a 0.2mm Nucleopore membrane. The concentration of NO_3-N in the extracts was measured by liquid chromatography, using a Dionex 4000i apparatus and a conductivity detector. WSP was measured by colorimetry and WSOC on a Dorhman DC-180 C analyser, which uses UV-persulfate oxidation and an IR detector. A separate analysis of variance was performed using the SAS system (10) at each sampling date, since the date x treatment interaction terms were significant.

RESULTS AND DISCUSSION

Climatic and yield data

The 1990 season was characterized by a wet spring in which rainfall was almost equivalent to PET. July was very dry and precipitations in the fall exceeded largely PET, leading to the recharge of the soil. The 1991 growing season was dryer than normal; mainly in June, July and September and significant recharge was not observed before the end of October. The movement of water through the soil profile was very limited during the 1991 growing season. In 1992, precipitations were unevenly distributed. In the spring, precipitations were almost average and below PET. The summer was very wet, especially in July where rainfall exceeded PET. Fall was dryer than the average, but precipitations were still larger than PET. For that specific year, recharge of the water table started in July and went on through the fall. Downward movement of water through the soil profile likely occurred in 1990 and 1992 but was limited in the 1991 season (data not shown). Average barley yields were higher in the CT-M system (3.87Mg ha^{-1}) whereas RT- DLM resulted in the lowest yields (3.44Mg ha^{-1}). Forage yields and nutritive quality were significantly better with RT than CT in 1992 only.

Effects of management practices on NO_3-N

Mean values calculated from all treatments for NO_3-N contents are presented in Fig. 1, for the 0-15 and 60-90cm layers at all sampling dates over the three growing seasons. Results obtained for the 15-30 and 30-60cm layers were in general intermediate to those presented and are not included. Beneath the 15-30cm layer, the NO_3-N contents measured were rather stable and always below the 10mg L^{-1}, which corresponds to the upper limit of nitrate recommended for drinking water. In 1990 and 1992, NO_3-N distribution in the 0-15cm layer, followed the same pattern: sharp decrease at the beginning of the season in that layer was observed from day 15 after seeding, indicating some plant uptake and possible leaching mainly in 1990. Higher NO_3-N content in the spring 1990 by comparison to values measured in 1991 and 1992, resulted from the plowing under of a good stand of alfalfa in the fall 1989.

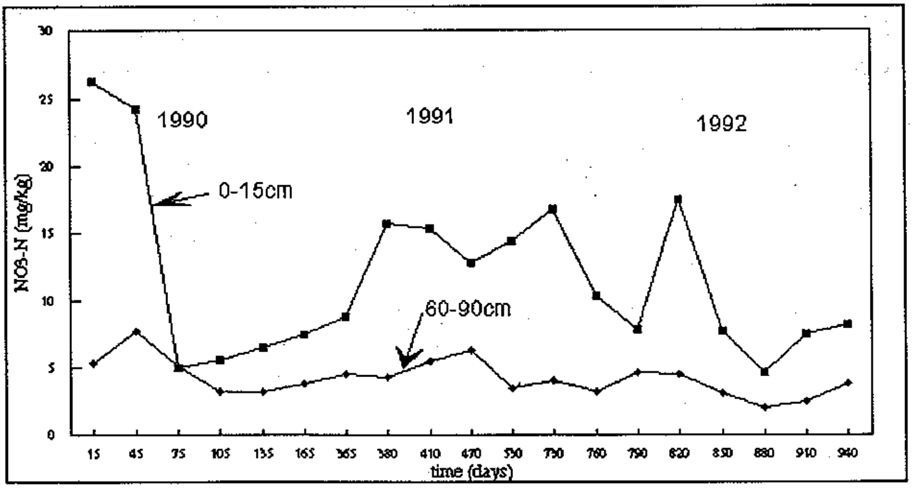

Figure 1. Temporal variation of NO_3-N

In 1991, a deficit of 90mm in precipitation during summer months coupled with poor growth of the crops, would explain higher NO_3-N content throughout the growing season in the top layer.

Analysis of variance showed the dominance of "cropping sequence" as single source of variation in NO_3-N content throughout the experimentation. "Tillage x fertilizer type" interaction was significant for the 0-15cm layer at 15 and 165 days after seeding in 1990. In early spring of that year (day 15), the content of NO_3-N in the 0-15cm layer, decreased in the following order: RT-M (40.9mg kg^{-1}), CT-M (28.8mg kg^{-1}), RT-DLM and CT-DLM with 18.8 and 17.5mg kg^{-1} respectively. The influence of cultivation practices was more emphasized under mineral fertilizers than with DLM; inorganic fertilizers being more readily available in the spring than organic sources of N.In the fall (day 165), after the primary tillage operation, RT-DLM presented the highest NO_3-N value (10 mg kg^{-1}) while in the CT-DLM combination plots, only 4.6mg kg^{-1} were measured. "Cropping sequence x fertilizer type" was also significant at days 105 and 165 in 1990. For example BU-M showed a significantly lower concentration (3.6mg kg^{-1}) of NO_3-N in comparison with CC-M (6.5 mg kg^{-1} and F1-M (6.4mg kg^{-1}). The fact that two crops contributed to the N uptake in the BU treatment may be responsible for the lower amount of NO_3-N measured in the soil solution. In the 60-90cm layer, contents were generally lower in plots with well established forage crops (F_2) by comparison to those with barley alone (CC). Intermediate values were measured in plots grown with barley underseeded (BU) and the first year of forage crops (F_1). Mineral fertilizer (M) led to higher NO_3-N values than DLM in that layer.

Effects of management practices on WSP

The analysis of variance showed that cropping sequence most frequently affected the WSP content in the top layer. Early in 1990, WSP concentrations were higher under CC and UB than under forages (Figure 2) due to slow establishment of forages seeded without cover crop but this trend was reversed later in the season because of the longer growing season of forage

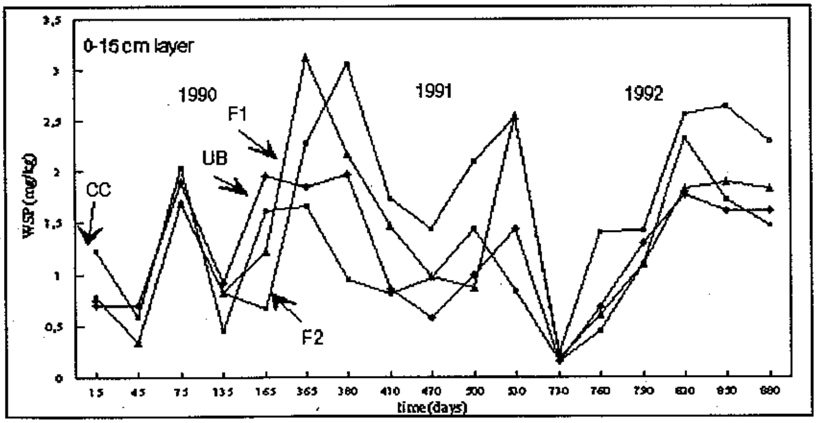

Figure 2. WSP distribution in the 0-15cm layer as function of cropping sequence.

crops and decline in root activity of barley following harvest.WSP values for soil under forage crops (F_1 and F_2) remained generally higher in 1991. A sharp decrease between the last sampling date in 1991 and the first in 1992 was observed throughout the profile for all cropping systems. In 1992, soil under well established forages (F_2) presented larger WSP contents related to greater root activity, whereas plots seeded with forages in 1992 (F_1 and UB) showed comparable WSP contents. Continuous barley (CC) generated high WSP content like in 1990, rapid decrease occurred soon after harvesting. Tillage practices had no significant effect on the WSP near the surfaceor on its movement to the subsoil in the three growing seasons. In the subsoil layer (60-90cm), WSP in plots with forages gradually increased from the beginning of the experiment and remained higher than that measured in plots with barley (CC and UB) till the end of 1991.

Effects of management practices on WSOC

WSOC in the 0-15cm layer decreased from 60mg kg^{-1} in 1990 to 35mg kg^{-1} on an average basis in 1991, whereas a reduction of more than 40% was observed in the 60-90cm layer for the same period of time. Tillage significantly affected WSOC (Figure 3).

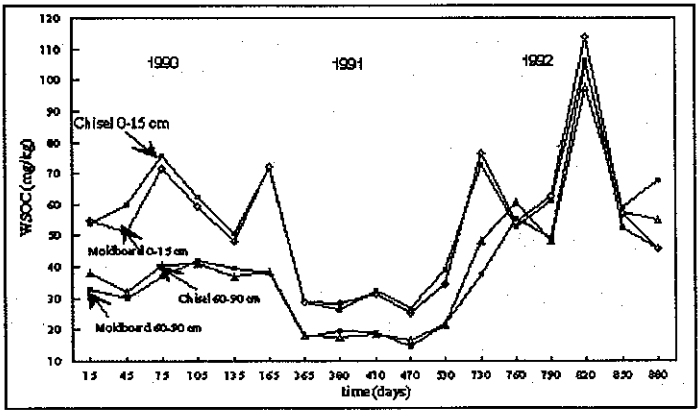

Figure 3.WSOC distribution in the 0-15 and 60-90cm layers as function of tillage

Values under chisel were higher than those measured under moldboard plow. Plowing a good stand of alfalfa in the fall of 1989 contributed to raise the amount of WSOC in the soil profile during the 1990 growing season as result of mineralization of crop residues. Curves obtained for WSOC in relation to the types of fertilization, presented the same trends as those in Figure 3. Addition of DLM as source of fertilizer contribute to raise WSOC in the 0-15cm layer early in the growing season (prior to 45 days) by comparison to mineral fertilizer and after 135 days in the 60-90cm layer. Microbial activity and crop yields were reduced by almost 50% in 1991 due to a drought. In 1992, both layers were enriched in WSOC by comparison to 1991 with maxima reaching more than 100mg kg^{-1} in both layers. Unusual low rainfall in the spring and summer favored biological activity and desorption of WSOC and its downward movement with water infiltrating the soil profile. Cropping sequences had little effect on the movement of WSOC within this experiment.

CONCLUSION

Over the three year period, distibutions of NO_3-N, WSP and WSOC in the 0-15 and 60-90cm layers of a clay soil profile were influenced by precipitations and downward movement of water during the growing season. Cropping sequence and types of fertilizers also played important roles in the amount of NO_3-N and WSP measured in both surface and subsoil samples. Higher contents in WSP and WSOC were obtained following application of organic fertilizer (DLM) whereas opposite trend was generally observed for NO_3-N. Efficiency of the crops to reduce NO_3-N losses in the profile is maximum with well established forage crops, on the other hand forage crops due to their longer vegetative season and higher rooting activity tend to generate more WSP which can be migrate down the profile and reach eventually the water table. Selection of management practices thus play an important role in the development of a sustainable environment in agriculture.

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EXPERIMENTAL INVESTIGATION AND MATHEMATICAL DESCRIPTION OF WATER AND MATTER TRANSPORT TROUGH SOIL MACROPORES

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ABSTRACT

The problem of matter transport in soils consists in estimating quantity of water and matter moved through macropores, physical regularity of sorption and changing ions in macropores,in basis of differentiation systems of soil porosity (macropores and occluded pores), and in developing of forecasting mathematical model. Lysimeter experiment shows that macropores are biological and soil nature, stable in space, the processes of changing and sorption are not intensive and are identical in different macropores. Mathematical model "AQUASALT" uses the division of water retention of different pore systems on the basis of primary scanning curves of hysteresis. Function of saturation of occluded pores is evalueted from the first order scanning curves of hystresis.

INTRODUCTION

The problem of matter transport in soil attracts attention because of use of different chemical substances in agriculture and increase of waste products. The decision in every particular case must be based on a physically based forecasting model, adopted on experimental basis. The specific peculiarity of transport in soil is conditioned by macropores which are the channels of quick movement of matter down the root zone clogging the ground water. The role of macropores in transport of water and matter in soils is dominant in any case: Bouma et al (1) noted that macropores occupied about 1% of porous volume conduct near 80% of water. Beven & Germann (2), Lawes et al (3) also found that main part of drained water moves through macropores. Skopp (4) and Beven & Germann (2) proposed that the main characteristic peculiarity of macropore transport is the quick transfer without (or very low) exchang with solid phase. The problem of water and matter macropores transport assessment consists in: 1) quantitative differentiation of systems of transport and occluded pores in soil, 2) defining main physical processes of water and chemicals transport, exchange in macropores and solid soil phase, and 3) developing physically based mathematical model for forecasting water and matter movement in soil macropores.

DESCRIPTION OF THE MODEL

Governing Equations

Consider a soil as a media with marcopores which are surrounded by soil matrix. The macropores have a mobile volumetric water content θm , while the bulk matrix has an immobile water content $S\theta_{im}$. We assume that convective transport of water and chemicals takes place only through macropores and can be ignored within the micropores of bulk matrix.

We can define total water content θ in the same way as was done by Zeiliger (5):

$$\theta=\theta_m+S\cdot\theta_{im} \tag{1}$$

where S is function of saturation of occluded pores, associated with air entry value, θ_{im} is immobile water content from water retention curve of occluded pores. We assume function of saturation S is function of the matrix pressure φ and the reversal value of pressure φ_i on the experimental primary scanning curves of soil-water relationships. Let us define function S for the first order drying scanning curves:

$$S_d(\varphi,\varphi_i)=1-a((\varphi_n-\varphi)(\varphi_i-\varphi_o))^b\exp(c(\varphi-\varphi_i)) \tag{2}$$

and for wetting scanning curves:

$$S_w(\varphi,\varphi_i)=1-d(\varphi-\varphi_o)^e(\varphi_i-\varphi)^f \tag{3}$$

where a,b,c,d,e,f are constants that must be determined from the primary and first order scanning curves of soil-water relationships, φ_o and φ_n are lower and upper boundary pressure on the primary curves (Fig. 1,2).

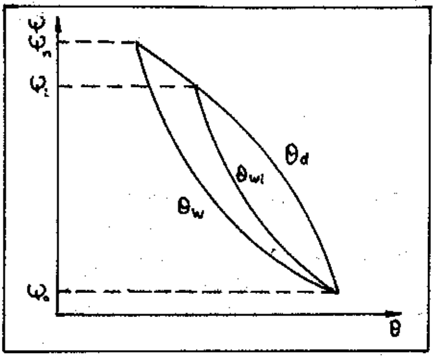

Figure 1.

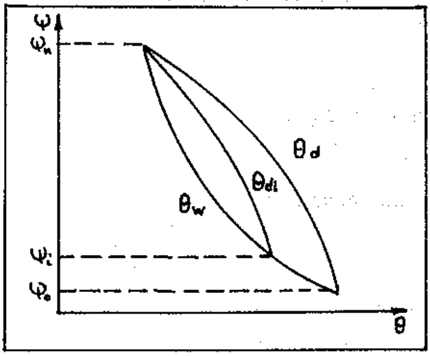

Figure 2.

Fig. 1,2. Primary θ_w wetting, θ_d dryind and the first order θ_{wi} wetting and θ_{di} drying scanning water retention curves.

One dimensional nonlinear water flow is described by Richards equation:

$$\frac{\partial\theta}{\partial t}=\frac{\partial}{\partial z}\left(K_w\frac{\partial H}{\partial z}\right)+I(z,t) \tag{4}$$

where t is time, K_w is hydraulic conductivity, $H=-\varphi-z$ is soil water potential, z is vertical distance and I(z,t) is source or sink term.

Now, we will make assumption that convective-dispersive transport of chemicals occur through macropores, with simultaneous diffusion into an occluded pores of matrix. Besides, chemical is adsorbed by as bulk soil matrix, so the surface area of the macropore walls. According van Genuchten et al (6) approach, the adsorption sites are divided into fraction (f_m) which is associated and in close contact with macropore solute, and another fraction is ($1-f_m$) associated with the bulk matrix.We assume also linear and reversible equilibrium adsorption in both fractions. So equations for convective-dispersive solute transport in both regions may be written similar to those used by van Genuchten et al (6) and Pachepsky (7):

$$\frac{\partial(\theta_m C_m)}{\partial t} + f_m \rho \frac{\partial S_m}{\partial t} = \frac{\partial}{\partial z}\left(\theta_m D_m \frac{\partial C_m}{\partial z} - q C_m\right) - E \tag{5}$$

$$\frac{\partial(\theta_{im} C_{im})}{\partial t} + (1 - f_m)\rho \frac{\partial S_{im}}{\partial t} = E \tag{6}$$

$$S_m = k \cdot C_m; \qquad S_{im} = k \cdot C_{im} \tag{7}$$

$$E = (C_{im} - C_m) / \tau \tag{8}$$

where Cm and Cim represent the average concentrations in the mobile and immobile liquid phases, Sm and Sim are the adsorbed concentrations of the macropore and micropore regions, fm is the mass fraction of the adsorbed concentration that equilibrates with the macropore liquid phase, ρ is the bulk density, q is the volumetric flux density,.Dm is dispersion coefficient of macropore regine, k is the average distribution coefficient of soil system,E and τ are the average rate and time of exchange between the two liquid phases.

Specification of the Parameters and Variables

In order to describe moisture movement in unsaturated soil, values of Kw, θm, θim, Sw and Sd for a given soil must be available for the whole range of soil moisture pressure.They must be available for the same conditions of bulk density and structure, and presumable for the same stage of wetting and drying as natural soil.

Experimental soil water retention data are well described by Zeiliger (7) equation:

$$\theta(\varphi) = (A - D)\exp(-(\frac{\varphi}{B})^C) + D \tag{9}$$

where A,B,C,D are empirical constants.Note that drying first order scanning curves begine from the primary wetting scanning curve.Subtracting equation for the first order wetting θwi(φ) scanning curves of soil water relationship from equation for the primary drying θd(φ) for reversal points φ=φi, we have:

$$\theta_d(\varphi_i) - \theta_{wi}(\varphi_i) = A_{im}\exp(-(\frac{\varphi_i}{B_{im}})^{C_{im}}) \cdot a((\varphi_n - \varphi_i)(\varphi_i - \varphi_o))^b \tag{10}$$

where Aim,Bim and Cim are constants of soil-water retention function of immobile pores. For estimating constants of Eq.[10] the method of Marquardt (8) is applied. Similarly, subtracting equation for any first order drying scanning curve from equation for the primary drying , we can evaluate constant c in Eq.[2].

Note that the value of the water content in Eq.[1] near saturation (φ=0) is defined as:

$$\theta(0) = A_m + A_{im} \tag{11}$$

Setting the value of the fraction mobile water content Φm=Am/θ(0) we can evaluate constants Am ,Aim and a. Finally,letting Dim =0 and substituting equation for mobile water content into Eq.[1] we can estimate the constants Bm ,Cm and D by approximation with method of

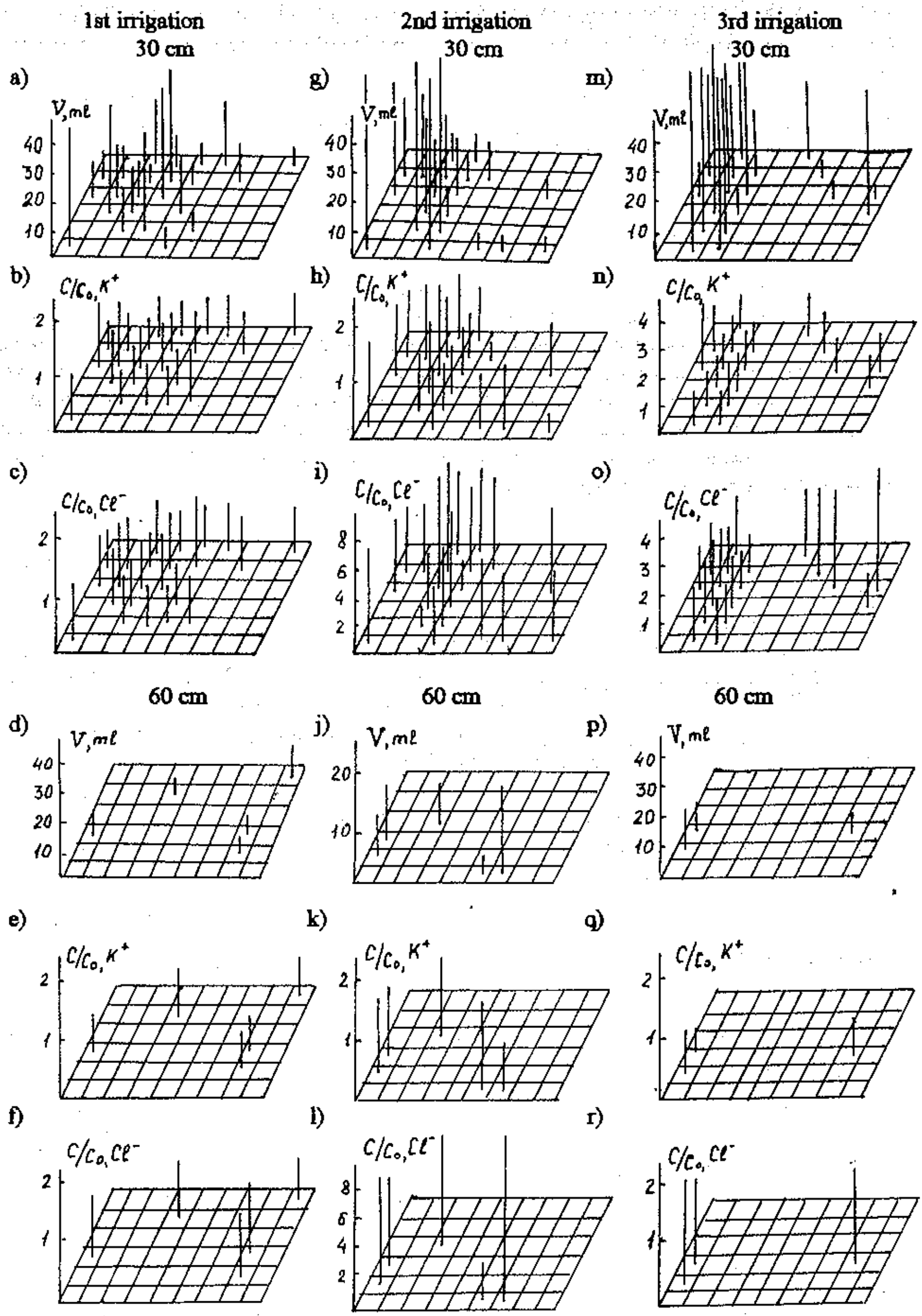

Fig.3 The distribution of water and relative concentration of K and Cl in lysimeter cells after irrigations.

Marquardt (8). The constants of function of saturation of occluded poresfor wetting Sw can be obtained from approximation of any first order wetting scanning curve by the same technique.

To evaluate the parameters of equations for convective-dispersive solute transport Eq.[5]-[8], the observed column effluent data and analytical solution of the one-dimensional transport equation described by Selim et al. (9) are used.

MATERIALS AND METHODS

The experiment on podzolic soil includes investigations of Cl and K movement by traditional method of soil-water (tensiometers, neutron moisture meter) and salt studies (soil-water extractions, vacuum porous caps), and also transport of ions through macropores by lysimeters (40x60 cm) with the cell's surface (58 cells) on the depths 30 and 60cm. The lysimeters were put in soil in special niches, taken out in 3-5 hours after the end of irrigation. The quantity of solution, concentration of ions K and Cl were determined in every cell. It was 3 irrigations during experimental period (june-september).1st irrigation was 50 mm of 0.05 n KCl solution, others - with natural water with low ions concentration.

RESULTS AND DISCUSSION

On the depth 30 cm in the cells of the lysimeter we collect water moved through macropores in quantity of 6.1% of 1st irrigation norm (Fig.3,a).The quantity of transported K was 4.7%,Cl - 6.5% of entered quantity (Fig.3,b,c).The relative concentration of Cl and K in different cells were close: Cl=1.1 and K=0.8. The same picture was on the depth of 60 cm (Fig.3,d-f).We can note the stability of macropore transport channels during 2nd and 3rd irrigations (Fig.3g-r) and that the process of ions exchange is very fast and restricted.

The model "AQUASALT" described accurately the phenomenon of salt and water transport in soil with macropores.The next task is the adaptation and choice of different models for prediction of water and matter transport in soil's macropores.

CONCLUSION

Macropores in soil are biological and soil nature, stable in space, the processes of ions changing and sorption are very fast, restricted and identical in different macropores. Mathematical model "AQUASALT" uses the division of water retention of different pore systems on the basis of primary scanning curves of hysteresis.The mass fraction of immobile water content for occluded pores is founded from the first order scanning curves of hysteresis. The model "AQUASALT" is useful for describing the processes of water and matter movement in structured soils with macropores.

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LOSSES OF MINERAL NITROGEN IN SURFACE AND DEEP RUNOFF FROM A FABA BEAN CROP (Vicia faba minor) ON A SLOPING SOIL WITH DIFFERENT TILLAGE METHODS.

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Abstract

Results are reported of a research on the effects of tillage methods on nitrogen losses in surface and deep runoff on a sloping soil cropped with faba bean (cv. "Chiaro di Torre Lama"). The research was conducted in 1991-93 on a clay-loam soil in a hilly area of Basilicata (Southern Italy), at 700 m a.s.l. on 600 m^2 plots with average slope 14%, ploughed along the maximum slope and distribuited in randomized blocks with 2 replications, one of which was hydraulically isolated.
The tillage methods compared were: ploughing at 40 cm + harrowing (A+E); scarifying at 50 cm + ploughing at 20 cm + harrowing (D+A+E); scarifying at 50 cm + harrowing (D+E); total weed control + harrowing (E).
Determinations of $N\text{-}NO_3$ and $N\text{-}NH_4$ were made on water samples collected separately from surface and deep runoff for each tillage method.
Of the 95 rainfall events recorded throughout the period December 1991 - September 1993, 32 resulted in surface runoff and 9 in deep runoff. Values of nitrogen (NO_3 and NH_4) concentration in surface runoff recorded in the first and second year were respectively 5.5 mg l^{-1} and 8.5 mg l^{-1} for A+E, 4.7 mg l^{-1} and 7.7 mg l^{-1} for D+E, 4.6 mg l^{-1} and 6.8 mg l^{-1} for D+A+E and 4.0 mg l^{-1} and 4.2 mg l^{-1} for E. The highest N concentrations for deep runoff samples were found in the second year in treatment E (11.9 mg l^{-1}).
Total nitrogen losses caused by surface and deep runoff during the period of observation were quite low. Values were highest (0.402 Kg ha^{-1}) for treatment E and lowest for D+A+E (0.279 Kg ha^{-1}).

Introduction

The introduction of legumes in modern crop systems is due to several reasons, largely related to the needs of environmental resources conservation (1). One of them is that food and fodder from legume crops may be produced without nitrogen fertilizers. In environments prone to erosion this may have important consequences on the limitation of nitrogen losses due to runoff. Infact, the amount of soluble N lost with surface runoff water is not related to the amount of nitrogen in the whole soil profile, but rather to the amount localized at the surface (2). Therefore, losses are strongly affected by the application of nitrogen to the soil with topdressing.
Great importance, of course, is to be ascribed to the amount and distribution of runoff. Several authors have reported that this amount can be affected by soil tillage (3). For these reasons, the Dipartimento di Produzione Vegetale of the Universita' della Basilicata is conducting research on losses of soluble nitrogen in runoff water from a legume crop in a sloping soil with different tillage methods.

Materials and methods

The research was conducted for two years (1991-93) on a faba bean crop (cv. "Chiaro di Torre Lama") in rotation with durum wheat. The location was a hilly area of Basilicata

(PZ) at 700 m a.s.l. on a clay-loam soil with average slope 14% and with the chemical and physical characteristics reported in table 1.
Four tillage methods were compared: ploughing at 40 cm + harrowing (A+E); scarifying at 50 cm + ploughing at 20 cm + harrowing (D+A+E); scarifying at 50 cm + harrowing (D+E); chemical weed control + harrowing (E). Each tillage method was tested on 600 m^2 plots, hydraulically isolated, with two replications tilled along the maximum slope.

Table 1 - Chemical and physical characteristics of the soil

Coarse sand (0,2<Ø<2 mm)	%	2.6
Fine sand (0,02<Ø<0,2 mm)	%	41.6
Silt (0,002<Ø<0,02 mm)	%	23.0
Clay (Ø<0,002mm)	%	32.9
pH		7.2
Organic matter	%	1.29
Total nitrogen (met. bichromate)	%	0.115
P_2O_5 available (met.Olsen)	ppm	58
K_2O available (met. ammonium acetate)	ppm	345

In order to test the effect of soil tillage on runoff and losses of solutes, surface runoff was collected. Deep runoff was sampled through a drainage tile placed at one end of each plot, perpendicular to the maximum slope and at 1 m depth.
Mineral nitrogen ($N\text{-}NH_4$ and $N\text{-}NO_3$) was determined with a DR 2000 Spectrophotometer on water samples collected after each runoff event.
Cultural practices are reported in table 2.

Table 2 - Cultural practices.

	1991/92	1992/93
Soil preparation		
a) tillage	October 1	October 20
b) seedbed preparation	10 d before sowing	
Sowing	December 5	November 6
Fertilization at sowing 100 units of P_2O_5	December 5	November 6
Harvest	July 8	July 1

Results and discussion

A value of 446 mm cumulated precipitation was recorded in the period December 20, 1991 - October, 1992, and 629 mm in the period November, 1992, - October, 1993. The seasonal distribution was more uniform in the first year when 51 precipitations events occurred and 20 of them gave surface runoff. In the second year the precipitation was more concentrated in the Fall-Winter period and most of it was snow. Of the 44 events only 12 resulted in surface runoff.
Runoff events were distributed quite uniformly during the first year (Fig. 1) following rainfall distribution. Events with runoff values higher than 1 mm occurred at the end of December and in October and corresponded to high intensity rainfall. In the second year

events with runoff values higher than 1 mm were recorded in December, January and March. Precipitations were limited in the summer and no runoff event was recorded.

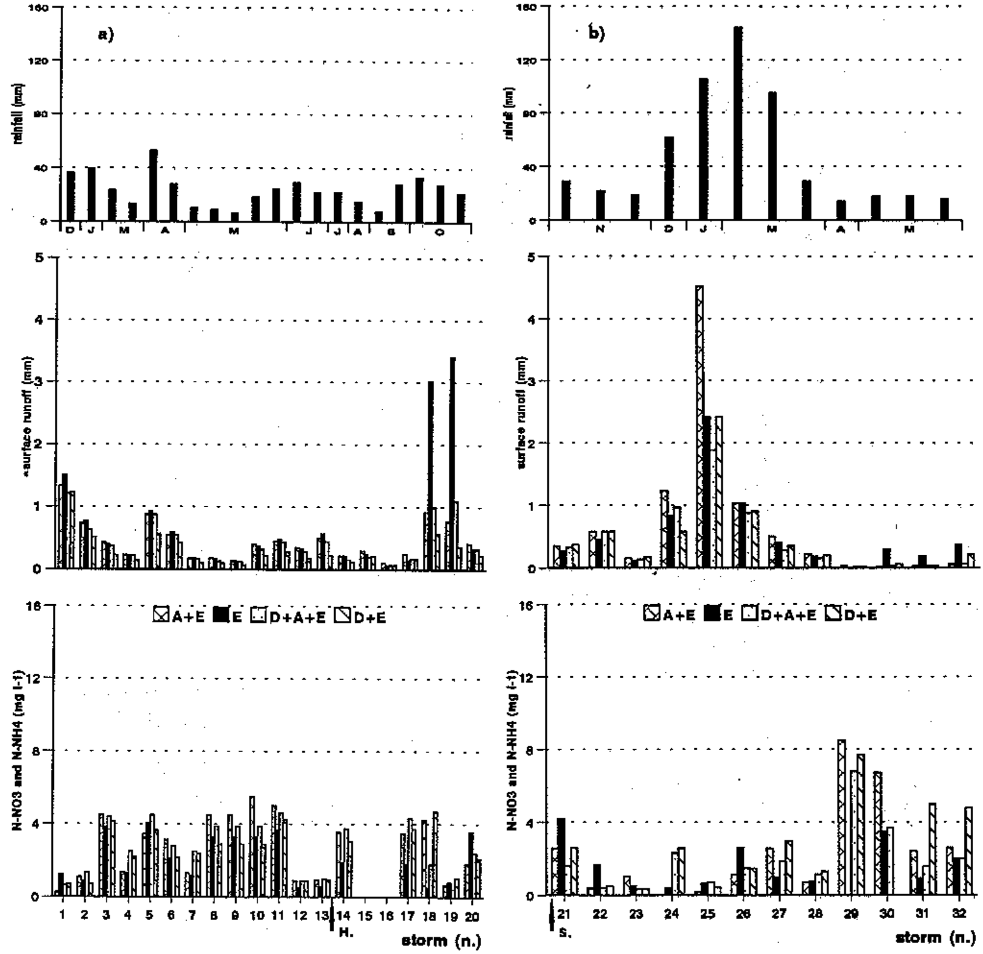

Figure 1 . Precipitation, surface runoff and N concentration recorded in each runoff event. H. = harvest; S. = sowing. a) 1991-92; b) 1992-93.

The highest values of mineral N concentration ($N\text{-}NO_3$ + $N\text{-}NH_4$) were recorded in both years in treatment A+E (5.5 mg l^{-1} and 8.5 mg l^{-1} for each year respectively) followed by D+E (4.7 mg l^{-1} and 7.7 mg l^{-1}), D+A+E (4.6 mg l^{-1} and 6.8 mg l^{-1}) and E (4.0 mg l^{-1} and 4.2 mg l^{-1}). The recorded concentrations are of the same order of magnitude of those reported by other authors (2; 4).
The time-course of mineral nitrogen concentration in surface runoff shows that in both years values were generally higher during the Spring period and were lower in events that occur after abundant precipitation.

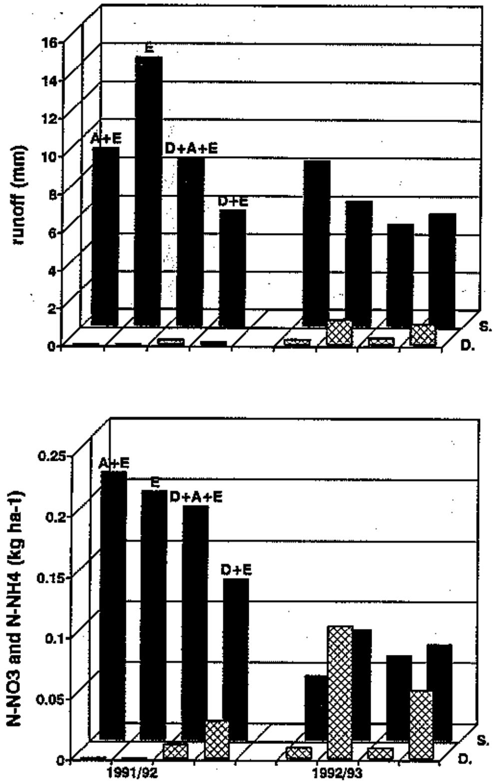

Figure 2. Total amount of runoff and nitrogen losses in each year. S. = surface runoff; D. = deep runoff.

Regarding deep runoff events, they were few (only 2 in the first year and 7 in the second year) and generally occurred at, or soon after, the most important precipitations. The concentration of mineral nitrogen was higher than that recorded in surface runoff, and reached values of 30.47 mg l^{-1} for D+E in the first year, and 11.9 mg l^{-1} for treatment E in the second year.

The total amount of yearly surface runoff (Fig.2) was different among tillage methods. Maximum values were 14.1 mm for E in the first year and 8.7 mm for A+E in the second year. Deep runoff was quite contained and values were higher in the second year with the maximum value of 1.3 mm for E.

The total amount of mineral N lost with surface runoff was highest for A+E (0.219 kg ha^{-1}) in the first year and for E (0.090 kg ha^{-1}) in the second year. Losses due to deep runoff in the first year were worth noticing only for chiseling treatments (0.011 kg ha^{-1} for D+A+E and 0.030 Kg ha^{-1} for D+E). In the second year lossess were higher with the maximum value in treatment E (0.109 Kg ha^{-1}).

Total values for the two year period indicate that the smallest losses of mineral N were reached with treatment A+E and D+A+E and amounted to 0.279 Kg ha^{-1}, followed by D+E (0.295 kg ha^{-1}) and E (0.402 kg ha^{-1}).

Losses of mineral nitrogen due to surface transport were limited, mainly because of the small runoff amounts that were recorded in the period under study.

Conclusions

Higher values of runoff and nitrogen losses were recorded in the first year characterized by events distributed more uniformly in time according to rainfall distribution. In the second year most precipitation consisted of snow, so that conditions were more favourable for infiltration than for runoff, and deep runoff and losses were relatively higher.

Losses of nitrogen ($N\text{-}NO_3$ + $N\text{-}NH_4$) were limited because of the small amount of runoff.

Regarding tillage, the highest values were found in E; in conclusion, treatment D+A+E proved the most effective in limiting runoff and consequent losses.

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LOSSES OF MINERAL NITROGEN IN SURFACE AND DEEP RUNOFF FROM A DURUM WHEAT CROP (Triticum durum Desf.) ON A SLOPING SOIL WITH DIFFERENT TILLAGE METHODS.

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Abstract

A research on the effects of tillage methods on nitrogen losses in surface and deep runoff was conducetd on a sloping soil cropped with durum wheat (cv. Appio) in 1991-93. The research site was a hilly area of Basilicata (Southern Italy), at 700 m a.s.l. on a clay-loam soil with average slope 14%. Plots had an area of 600 m^2 and were ploughed along the maximum slope and distribuited in randomized blocks with 2 replications, one of which was hydraulically isolated. The tillage methods compared were: ploughing at 40 cm + harrowing (A+E); scarifying at 50 cm + ploughing at 20 cm + harrowing (D+A+E); scarifying at 50 cm + harrowing (D+E); total weed control + harrowing (E). Determinations of $N\text{-}NO_3$ and $N\text{-}NH_3$ were made on water samples collected separately from surface and deep runoff for each tillage method. Of the 95 rainfall events recorded throughout the period December 1991 - September 1993, 32 resulted in surface runoff and 12, in deep runoff. Values of nitrogen (NO_3 and NH_4) concentration in surface runoff recorded in the first and second year were respectively 8.9 mg l^{-1} and 15.6 mg l^{-1} for A+E, 5.8 mg l^{-1} and 4.9 mg l^{-1} for D+A+E, 5.7 mg l^{-1} and 13.2 mg l^{-1} for E and 5.6 mg l^{-1} and 6.0 mg l^{-1} for D+E. Total nitrogen losses caused by surface and deep runoff during the period of observation were quite low. Values were highest (0.406 Kg ha^{-1}) for treatment E and lowest for D+A+E (0.297 Kg ha^{-1}).

Introduction

The runoff of water from agricultural fields and the consequent transport of solids and solutes is one of the problems of natural resources conservation and environmental protection. Recent research has shown the significant influence of tillage methods and soil cover (with crops or residues) on the amount of runoff and transport of solids, and also on the yield response of crops (1).

Regarding soil tillage methods, conservative techniques have been proposed (minimum tillage, shallow tillage, rototillage, scarifying) to reduce soil and water losses compared to conventional tillage (2; 3; 4). The hilly areas of southern Italy present unfavourable physical conditions (rainfall distribution, duration and intensity; nature and slope of soils) that make them prone to erosion. The study of runoff and the consequent transport of solids and solutes as affected by cropping systems is therefore of interest in such areas. Cereals are the main crops in those environments; soil tillage (5; 6) and nitrogen fertilization (7) are the techniques farmers most rely upon in order to obtain higher yields.

Therefore, the Dipartimento di Produzione Vegetale of the Universita' della Basilicata is conducting research on the effect of soil tillage on nitrogen losses in surface and deep runoff on a durum wheat crop.

Materials and methods

The research was conducted for two years (1991-93) on a durum wheat crop (cv. "Appio") in rotation with faba bean. The location was a hilly area of Basilicata (PZ) at 700 m a.s.l. on a clay-loam soil with average slope 14% and with the chemical and physical characteristics reported in table 1.

Four tillage methods were compared: ploughing at 40 cm + harrowing (A+E); scarifying at 50 cm + ploughing at 20 cm + harrowing (D+A+E); scarifying at 50 cm + harrowing (D+E); chemical weed control + harrowing (E). Each tillage method was tested on 600 m^2 plots, hydraulically isolated, with two replications tilled along the maximum slope.

Table 1 - Chemical and physical characteristics of the soil

Coarse sand	(0,2<Ø<2 mm)	%	2.6
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Silt	(0,002<Ø<0,02 mm)	%	23.0
Clay	(Ø<0,002mm)	%	32.9
pH			7.2
Organic matter		%	1.29
Total nitrogen (met. bichromate)		%	0.115
P_2O_5 available (met.Olsen)		ppm	58
K_2O available (met. ammonium acetate)		ppm	345

Surface runoff was collected in containers of 1 m^3; deep runoff was sampled through a drainage tile placed at 1 m depth, at the lower end of each plot, perpendicular to the maximum slope.
Water samples of surface and deep runoff collected after each event, and mineral nitrogen ($N\text{-}NH_4$ and $N\text{-}NO_3$) was determined with a DR 2000 Spectrophotometer.
Cultural practices are reported in table 2.

Table 2 - Cultural practices.

	1991/92	1992/93
Soil preparation		
a) tillage	October 1	October 20
b) seedbed preparation	10 d before sowing	
Sowing	December 4	December 2
Fertilization at sowing	December 4	December 2
36 units of N		
92 units of P_2O_5		
Top fertilization		
104 units of N	February 18 March 31	February 15 April 15
Harvest	July 16	July 14

Results and discussion

A value of 446 mm cumulated precipitation was recorded in the period December 20, 1991 - October, 1992, and 629 mm in the period November, 1992 - October 1993. The seasonal distribution was more uniform in the first year, when 51 precipitation events occurred and 20 of them gave surface runoff. In the second year the precipitation was more concentrated in the Fall-Winter period and most of it was snow. Of the 44 events only 12 resulted in surface runoff.
In the first year (Fig.1a) events with runoff values higher than 1 mm occurred at the end of December and in October and corresponded to high intensity rainfall. In the second year (Fig.1b), runoff values higher than 1 mm were recorded in December, January and March, while during the Summer precipitations were limited and no runoff event was recorded.

Regarding the concentration of mineral N ($N\text{-}NO_3 + N\text{-}NH_4$) in surface runoff, treatment A+E showed the highest average values in both years (2.7 mg l^{-1} and 3.4 mg l^{-1} respectively). In the first year maximum values reached 8.9 mg l^{-1} for treatment A+E, followed by D+A+E with 5.8 mg l^{-1}, E with 5.7 mg l^{-1}, and D+E with 5.6 mg l^{-1}; in the second year maximum concentration values were 15.6 mg l^{-1} for A+E, 13.2 mg l^{-1} for E, 6.0 mg l^{-1} for D+E, 4.9 mg l^{-1} for D+A+E. The recorded concentrations are of the same order of magnitude of those reported by other authors (3; 8).

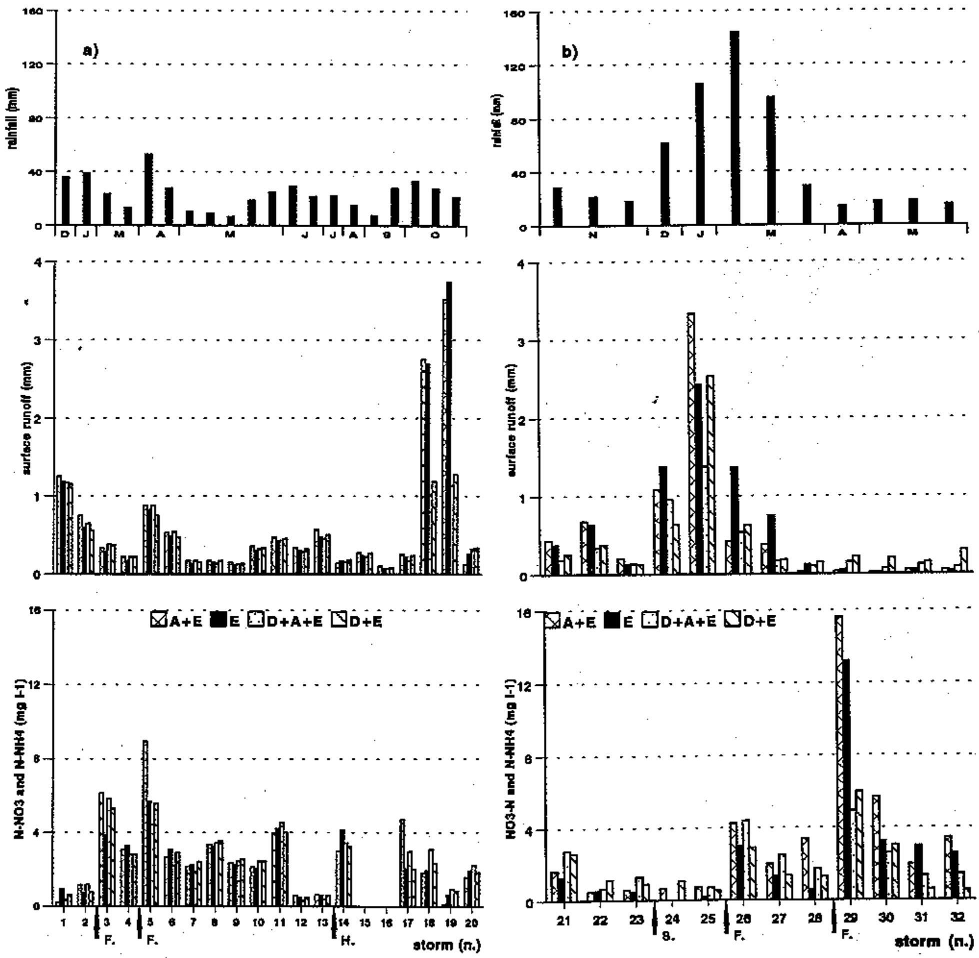

Figure 1. Precipitation, surface runoff and N concentration recorded in each runoff event. F. = top fertilization; H. = harvest. S. = sowing. a) 1991-92; b) 1992-93.

It is also remarkable that for all tillage treatments the highest values of nitrogen concentration with surface runoff occurred in the first event after top-fertilization. A similar effect of topdressing is reported by other authors (3;8).

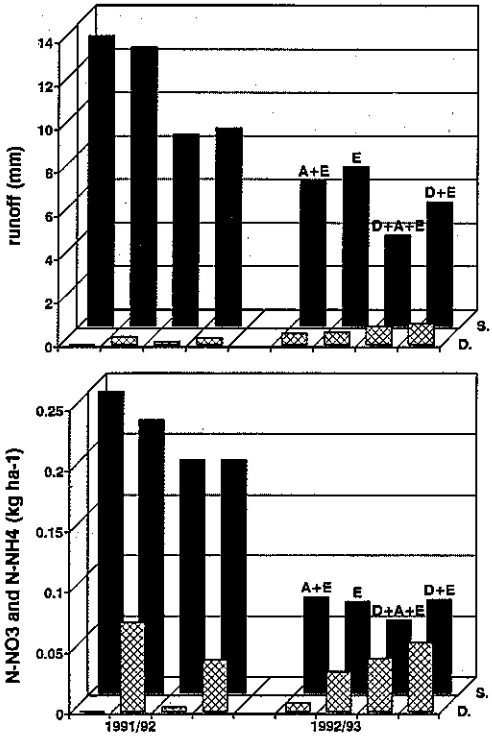

Figure 2. Total amount of runoff and nitrogen losses in each year. S. = surface runoff; D. = deep runoff.

The total amount of yearly surface runoff (Fig.2) was different among tillage methods. Maximum values were 13.0 mm for A+E in the first year, and 7.2 mm for E in the second year. Deep runoff was quite contained and values were higher in the second year. The highest value (0.9 mm) was recorded in treatment D+E.

The total amount of mineral nitrogen lost in each year with surface runoff was highest for A+E (0.248 kg ha^{-1} in 1991-92 and 0.079 kg ha^{-1} in 1992-93).

Losses due to deep runoff were smaller in spite of high concentrations recorded (peak values of 25.9 mg l^{-1} for E in the first year and 9.3 mg l^{-1} for D+E in the second year). This can be explained with the small runoff amounts recorded in both years. Total values were highest in treatment E for the first year (0.073 kg ha^{-1}) and in treatment D+E in the second year (0.043 kg ha^{-1}).

The total losses in both years, due to cumulated values for surface and deep runoff were lowest in D+A+E (0.297 kg ha^{-1}), followed by A+E (0.334 kg ha^{-1}), D+E (0.368 kg ha^{-1}) and E (0.406 kg ha^{-1}).

Recorded values were quite contained compared to those reported by other authors (3; 8) because of the small amounts that were measured in the period under study.

Conclusions

Rainfall distribution was very different in the two years, and both runoff and nitrogen losses were higher in the first year.

Losses of mineral nitrogen were small, essentially due to the small amount of runoff, and they were affected by topdressing with nitrogen fertilizers.

Regarding tillage, the highest N losses occurred in the highest runoff with conventional tillage. In conclusion, treatment D+A+E proved the most effective in limiting losses of soluble nitrogen.

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EVALUATION OF INCREASED EROSION RISKS ON SLOPES WITH WHEEL TRACKS

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ABSTRACT

For the forecast of expected onsite and offsite damages it is anavoidable to estimate the "man made " paths of erosion in the agriculture land use.The main paths for runoff and sediment losses by water erosion are the wheel lanes and ruts arising from intensive production on arable lands.

The results of experiments for classifikation of traffic lanes as paths on the soil surface will be presented. The different kinds of lanes without plants and ruts with low plant cover for rotational cropping of winter wheat, silage maize,potatoes and sugar beets were investigated with regard to infiltration rate.. In comparison with rain classification it is possible to characterize erosion paths coused by soil management.

INTRODUCTION

The danger of loss in soil fertility by water erosion exists on 250.000 ha of soils derived from wurmian moraine in North and East Germany. One of the most important problems consists in a very high vertical and horizontal variability of soil parameters like particle size distribution, horizon depth, field capacity, humus and nutrient content, capacity of infiltration and aggregate stability. An other result of glacial activity are more than 40.000 lakes, rivers, streams and other water protection areas. The main paths for runoff and sediment losses are the wheel lanes and ruts arising from intensive production on arable lands. The structure of the topsoil and of the subsoil is often damaged as a result of too frequent traffic with heavy machines and transport vehicles, which exert high specific ground pressures because their wheels have to support high axial loads.An integration parameter characterizing the damage of soil structure caused by vehicle traffic is bulk density. As a result of the increased compaction, the direction and intensity of water movement on the soil surface and into the soil body are changed. A high part of rain water does not infiltrate but produces runoff. On slopes of about 4% inclination, wheel tracks are the prefered water ways, resulting from a low infiltration rate and a high transport volume. These transport ways change their form from rills to ditches. The runoff processes increase , carrying nutrients and pesticides and pollutants into streams or water areas or other neighbouring biotopes in the landscape, forming the offsite damages of erosion.

For the forecast of expected onsite and offsite damages it is anavoidable to estimate the "man made" paths of erosion in the agriculture land use. The application of the USLE (1) or ABAG (2) with the factor C for management and land use was not successful, so far, because rill erosion and other linear forms of erosion, as well as their dynamics, are not accounted for in these models.

In the following results of experiments for classification of traffic lanes as paths for runoff and sediment transport on the soil surface will be presented. The different kinds of lanes without plants and ruts with low plant cover for rotational cropping of winter wheat, silage maize, potatoes and sugar beets were investigated with regard to infiltration rate, transport volume of runoff and lane distribution on the fields. In comparison with rain classification (3) it is possible to characterize the erosion paths caused by soil management.

MATERIAL AND METHODS

Analysis of soil load impacts

Strip-wise or mosaic-like occurence is a typical feature of technogenic damage to the structure of tilled soils. The patterns of distribution reflect the different traffic lane positions, pressures, loads, and frequencies of wheel passes during the past management cycle (4).

For estimating and valuing the degree of soil load by the present production processes rightly, detailed analyses of wheel equipment effects must be carried out. The load impacts resulting from the running gears of farm machinery and transport in various field operations and operation sequences and in the rotation of crops, respectively, have been analyzed as follows: The field area is subdivided into small sections (1...5 cm), and the track position which each wheel takes in the course of field operations is fixed true to scale and location. At an imaginary line at right angles to the main working direction, the wheel passes are counted and classified graduatedly for wheel load and specific pressure (inflation pressure) (5).Table 1 shows the proportional traffic area for common plant production techniques.

Table 1: Traffic characteristics (proportions of wheel tracks after harvest of winter wheat, potatoes, sugar beets and silage maize, % of cultivated area, without primary tillage) represented for common production methods

1.1 Trafficked areas

crop	reference width*	trafficked area	trafficked area total **
	m	per cent	per cent
potatoes	4,5	97,8	552,2
sugar beets	2,7	88,9	981,0
silage maize	5,0	66,0	344,0
winter wheat	5,0	61,0	481,0

* machine width of the main systems in East-Germany

** considering repeated wheeling of traffic lanes

1.2: Classification of pressure (kPa)

	moderate		medium		heavy	
	< 150		150 ...200		>200	
	area (%)		area (%)		area (%)	
crop	trafficked	total	trafficked	total	trafficked	total
potatoes	15	83	29	158	56	311
sugar beets	0	0	53	524	47	457
maize	12	40	22	76	66	228
winter wheat	19	92	34	164	47	225

Estimation of infiltration rate

The infiltration rate was measured in and between the wheel lanes with "double ring infiltrometers" (6). The soil between the rings was saturated with water. The measurements were taken in the middle ring. The data were averaged from 10-20 single infiltrometers , the divergence from the mean value (s) being an additional parameter.These data were compered with rain classes by KOHNKE (7): low infiltration: < 20mm. h^{-1}; middle infiltration: 20...100 mm . h^{-1}; high infiltration: > 100 mm . h^{-1}

Runoff and soil loss determinations

Based on the analyzed extent and frequency of soil loading in practice, a field experiment was conducted with simulated traffic lanes.Permanent traffic lanes were established on plots with different depth of soil tillage.Every time field operations for seedbed preparation, for sowing, for post-cultivation and for harvest was done, the "model-traffic lanes" were used for the necessary number of wheel passes.

The wheel passages were realized with a special running gear device in two different load levels with tyres on the border of load capacity (I. 80 kPa inflation pressure, 17,5 kN wheel-load; II. 300 kPa / 35 kN).

One part of the experimental field was inclined with a slope of 7%. In this part the soil surface runoff and soil loss were measured after a distance of 30 m inside and between the traffic lanes. Runoff and sediment transport into neighbouring biotopes were mapped following (7 , 8)

RESULTS AND DISCUSSION

Soil loss and nutrient loss

Soil loss amounted to12 ...19 t from ha .a^{-1} in the mean of plots.The soil loss of the traffic lanes amounted to 15 ... 35 t . The loss of carbon, nitrogen and phosphorus are shown in fig1.

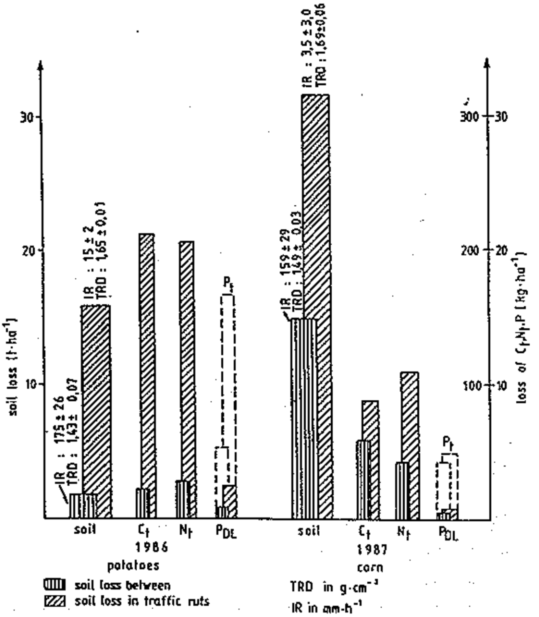


Figure 1: Total soil and nutrient losses in and between traffic lanes on potatoes and maize fields from May- August (TRD = bulk density ; IR = infiltration rate)

Change of infiltration rate

High traffic frequency affected the amount of conducting macropores (GP I : diameter > 50µm;

GP II : diameter 10 to 50 µm) , thus decreasing bulk density and infiltration rate in the traffic lanes (Table 2).

Table 2: Change of conducting macropores (GP I: diameter > 50µm , GP II: diameter 10 to 50 µm), bulk density and infiltration rate due to loading by traffic vehicles in wheels

soil kind		sandy soil		loamy -sandy soil	
pressure	kPa	0	300	0	300
bulk density	$g.cm^{-3}$	1,43a	1,65b	1,49a	1,69b
GP I	vol-%	15,90a	4,30b	11,70a	7,20b
GP II	vol-%	12,60a	7,80b	15,00a	7,10b
IR	$mm.h^{-1}$	175,00a	15,00b	159,00a	1,00b

Although variability was high, there was a significant correlation between bulk density and infiltration rate , measured in more than 40 examples (fig.2).

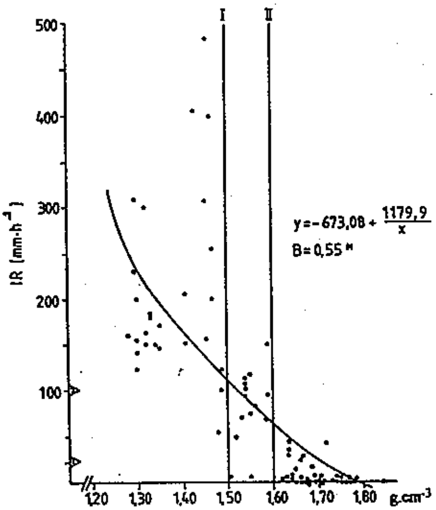


Figure 2: Correlation between bulk density and infiltration rate (IR) on slopes
GW I: limit value of the optimal bulk density range of tilled top sandy soils
GW II: limit value of the bulk density range with the beginning of long-term damages 1 2 infiltration classes according by KOHNKE

In comparison with the rain infiltration classes by KOHNKE, most of the values found in the traffic lanes were in the low class <20 $mm.h^{-1}$.

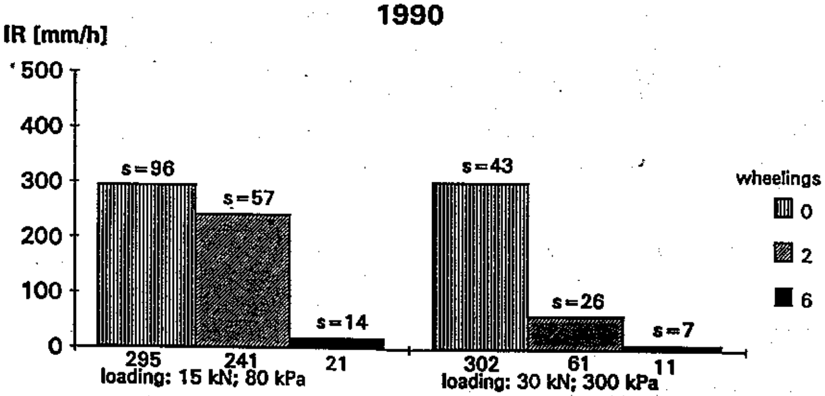
These differences were observed for all years and all crops (table 3).

The estimation of the differences between the number of wheelings , the increase of wheeling frequency and the change of infiltration rate of the lanes caused by repeated traffic with different loads during a vegetation period is very important. With the quantification of this parameter it is possible to estimate the dynamics of runoff and sediment transport paths throughout a year.

The results of the experiment with defined wheelings (1...10 passes) and defined loading (two steps) on 15 cm deep tilled soil pointed out the strongest infiltration decrease after 2 wheelings (1990) or 2+2 = 4 wheelings (1991) for a pressure of 300 kPa every time (figure 3). A pressure of 80 kPa decreased the infiltration after 6 wheelings.

Table 3: Change of infiltration rate in traffic lanes on sandy soils and comparison with classification by KOHNKE

year	crop	pressure kPa	bulk density g.cm-3	infiltration rate mm.h-1	variability s	infiltration KOHNKE
1988	potatoes	0	1,48 a	175 a	35	high
	n=60	300	1,67 b	30 b	10	mean
1990	maize	0	1,32 a	148 a	48	high
	n=60	300	1,66 b	<1 b	<1	low
1991	wheat	0	1,30 a	55 a	19	mean
	n=60	300	1,54 b	11 b	9	low
1992	potatoes	0	1,56 a	85 a	14	mean
	n=240	300	1,72 b	5 b	<1	low



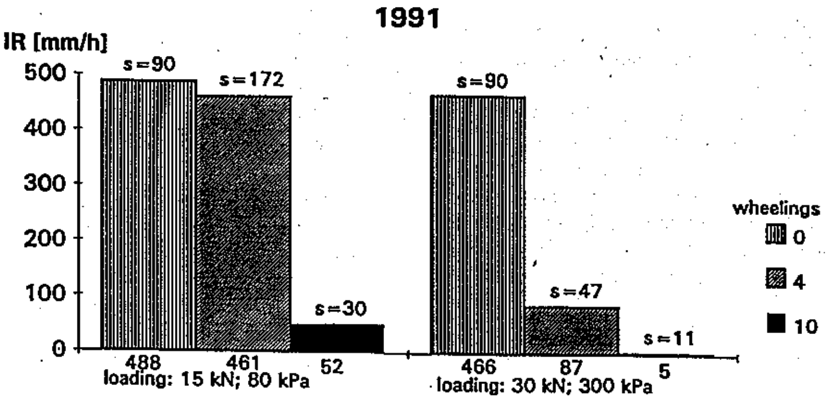


Figure 3 : Change of infiltration rate by 2 , 4, 6 and 10 wheelings with a pressure of 80 and 300 kPa, a loading of 15 and 30 kN and 15 cm deep tillage on a sandy soil

CONCLUSION

1. The condition of the soil surface, a minimal roughness and a low level of microrelief due to the process of surface sealing , entails the beginning of runoff and splash erosion in the inter- rill areas (*Helming, 19..., Roth, 19...*).The erosion and runoff processes change from inter-rill into rill areas during stronger rain events (Hartmann) . Traffic lanes and ruts are the most important erosion and runoff paths on arable land.
2. Large parts of arable fields are loaded with excessive pressures and weight. Trafficked areas with repeated wheel passes are endangered in particular. Repeated traffic causes permanent harmful compactions even in subsoil layers. Heavily compacted soil structures will hardly be able to regenerate.
3. Trafficked areas with more than 2 to 4 passes show a extremely low level of infiltration capacity . The part of arable areas with infiltration rates < 100 mm per h (= medium to low , KOHNKE) increases from seedbed preparing up to harvest operations in the vegetation period. Therefore the real soil erodibility grows too and it is necessary to estimate the dynamics of it.
4. Crop production is impossible without traffic vehicles. As in most of the ecological damages that are due to technogenic reasons, prevention is also to the only successful solution in the long run in run terms of field compaction.The most important factors include soil-preserving implements, combination of field operations, sufficient traction power, reduced intensity of tillage, reasonable field dimensioning.
5.In view of erosive water flow in ruts and traffic lanes, the possibilities to open the "traffic pans" for infiltration of rain water should be considered. There is need for new ideas and further development in this direction.
6.Another possibility is the interruption of paths and water ways by filter strips between arable land and neighbouring biotopes. To date, there is not enough experience with respect to this problem about this.

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ROTATION, TILLAGE AND RESIDUE MANAGEMENT EFFECTS ON RAINFALL INFILTRATION AND SOIL EROSION

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ABSTRACT

A mobile rainfall simulator was used on experimental plots where crop rotations, tillage practices, and stubble management treatments have been studied for up to 16 years. Erosive simulated rainfall (100 mm/hr) was used during autumn, 1-3 months before sowing in order to assess the effects of the treatments. The red-brown earth soils at the experimental sites are susceptible to degradation due to inherently poor soil structure and low organic matter contents, exacerbated by a change from cereal-pasture rotations to continuous cropping with cereals and grain legumes.

Infiltration is inversely related to runoff, soil loss and nutrient loss and thus is an indicator of the long-term sustainability of soil management practices. No-till systems had higher infiltration than systems using conventional cultivation (up to four passes before sowing). No-till was particularly good in combination with a cereal-pasture rotation, where the increased infiltration is associated with extra transmission pores created by pasture roots, increased earthworm burrows and increased organic matter and thus more stable soils than those under continuous cropping. Crop stubble retention on the soil surface favoured infiltration in comparison with stubble harvesting or burning. Research results and farmer experience generally agree that 3 t/ha is required to reduce the erosion risk on red-brown earths to acceptable levels.

The data show that sound rotations, reduced tillage and retention of crop residues are important components of conservation land management systems and sustainable crop production.

INTRODUCTION

Most of Australia's soils are old, highly weathered and, in their natural state, deficient in plant nutrients, especially nitrogen and phosphorus. Many of these soils have been farmed since the 1850's. Wheat yields initially declined through nutrient exhaustion but from 1900, with the use of superphosphate, fallowing and new varieties, yields gradually returned to their initial levels. However, the exploitive wheat-fallow rotation led to a loss of soil fertility and soil structure, and resulted in widespread soil erosion by wind and water during the 1930's and 1940's. From about 1950, due mainly to the adoption of cereal-legume pasture rotations (ley farming) which restored soil nitrogen and improved the soil physical condition, a marked increase in wheat yields has occurred. In the past fifteen years, economic circumstances have encouraged farmers to crop more intensively and many have adopted a continuous cropping rotation using cereals, grain legumes and oilseed crops. With these practices, the soils of our cropping areas are again at risk of degradation.

Problems found in many of South Australia's red-brown earth soils include: a decline in soil organic matter; a decline in soil structure; increased crust formation (on flat land); reduced infiltration; increased runoff, soil and nutrient loss; and reduced crop emergence and grain yield due to these factors.

Long-term experiments have shown that crop rotations, tillage practices and residue management affect soil organic matter and hence chemical and physical soil properties. This paper reports the results obtained on the experimental plots when a mobile rainfall simulator was used to assess the effects of the treatments on rainfall infiltration and soil erosion.

MATERIALS AND METHODS

Sites and soils

The rainfall simulation studies were done on three existing long-term experiments and on farms on red-brown earth soils in the cereal growing areas 80 - 120 km north of Adelaide in South Australia. The experiments have been running for up to 16 years. They are monitoring the effects of key management practices on crop production and soil factors. The experimental treatments include:

(i) *Rotations*
- a) pasture-wheat (PW). An annual legume-dominant pasture based on medics and subterranean clover alternates with wheat.
- b) wheat-barley-grain legume (Ccrop). Continuous cropping (one crop per year) with cereals and grain legumes.

(ii) *Tillage*
- a) no-till (NT). Sowing with narrow points into uncultivated soil. Weeds before sowing are controlled with herbicides.
- b) conventional cultivation (CC). Cultivation for weed control (3 passes) before sowing with normal (150 mm) points.

(iii) *Stubble management*
- a) stubble mulched (chopped) and retained on the soil surface each year at rates averaging 0.5, 3 and 5 t/ha.
- b) stubble grazed by sheep at a high stocking rate before rainfall simulation.

Details of one of the long-term experiments, and some soil and agronomic data have been reported elsewhere (1).

Rainfall simulation

The Northfield Rainfall Simulator and accessory equipment were used to study the effect of the treatments on infiltration, runoff, and soil and nutrient loss. An intensity of 100 mm/hr, typical of an erosive rainstorm, was used for a period of 18 minutes, giving a basal rain of 30 mm. This intensity was chosen because of the need to maximize the number of simulation runs and measurements per day; previous research had shown that differences in rates of rainfall infiltration associated with land management treatments become evident after 6 - 9 minutes of simulation at this intensity. At 100 mm/hr, the simulator produced drop size, fall velocity and impact energy characteristics similar to those of natural rainstorms (2), with a mean drop terminal velocity of 7.5 m/s. Details of the rainfall simulator and methods for the study of infiltration, runoff and soil and nutrient losses are available (3). Measurements included soil surface condition and surface cover, runoff (collected at 3 minute intervals), amount of sediment in the runoff and the concentration of nitrogen and phosphorus in the sediment.

RESULTS AND DISCUSSION

In the long-term experiments, crop production and soil factors have been measured regularly, to assess the effect of the rotation, tillage and stubble treatments. The results being obtained are illustrated by data from one site (Figure 1). Soil organic carbon and total nitrogen values in the 0 - 10 cm layer have been combined to calculate a soil fertility index which reflects the change in soil organic matter over a period of time. Where exploitive land management practices are used (conventional cultivation, stubble harvested, 0 kg/ha N), all rotations have lost fertility over a 16-year period. The losses range from 1% (wheat-legume pasture) to 19.5% (continuous cereals). Where conservation-based practices have been used (no-till, stubble retained, 80 kg/ha N applied to the wheat phase), the fertility index is higher in all rotations, from +19% (wheat-legume pasture) to -8.5% (wheat-fallow).

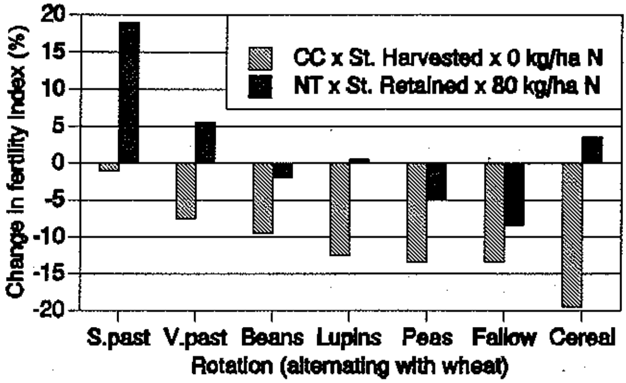

Figure 1 Change in the soil fertility index from 1977 to 1993, showing the effect of crop rotation, tillage practice, stubble management and N fertiliser. (S.past = sown legume pasture; V.past = volunteer grass pasture).

Wheat yields and grain protein percentages generally follow the trends in soil fertility. Experimental plots covering a range of soil fertility values as indicated above, were selected for rainfall simulation studies.

The effect of rotation was studied by comparing two continuous cropping rotations (wheat-wheat and wheat-beans) with a wheat-legume pasture rotation. The simulator runs were done on adjacent 1 m x 0.5 m areas with existing cover (as would exist on a farm using conservation farming methods) and with the cover removed, to simulate the situation where crop residues are mechanically removed or burned before sowing the next crop (Figure 2). In all these rotations, the runoff was less where the existing cover was retained than on the bare soil areas and the wheat-legume pasture rotation had less runoff than the continuous cropping rotations. The legume pasture has stabilized soil aggregates to allow a high infiltration rate, especially with vegetative cover present.

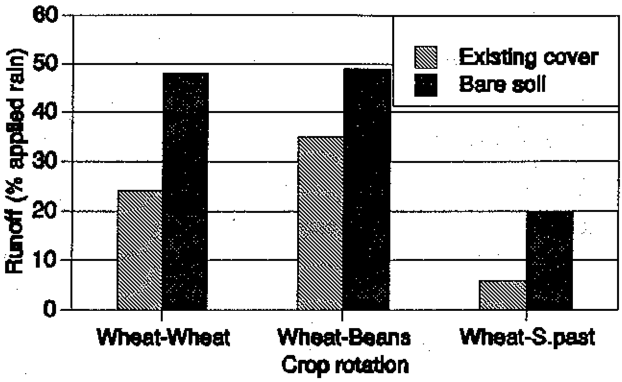

Figure 2 Runoff as affected by three rotations and two surface cover conditions. (S.past = sown legume pasture).

Further evidence of the benefits of a wheat-legume pasture rotation and stubble retention was obtained at another site where NT and CC treatments were also applied (Figure 3). These data show that the effects of rotation, tillage and stubble management are cumulative - they all contribute to soil stability and hence to a reduction in runoff.

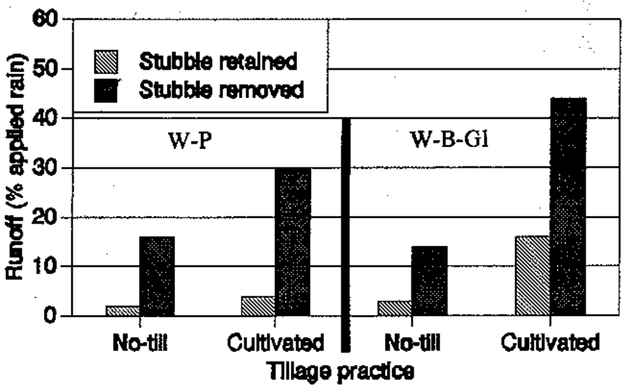

Figure 3 Runoff as affected by rotation, tillage and stubble management. (W-P = wheat-pasture; W-B-Gl = wheat-barley-grain legume).

The effectiveness of stubble cover as a means of protecting the soil from raindrop impact and maintaining an open surface structure depends on the actual amount retained. Increasing amounts of stubble cover increased infiltration and reduced runoff and soil loss on a 5% slope (Figure 4). At least 2 - 3 t/ha of cereal stubble (60 to 75% ground cover) is required to protect sloping soils from excessive erosion. In the same experiment, the eroded sediment was a mixture of aggregates and primary particles carrying with it a high concentration of N and P (Figure 5).

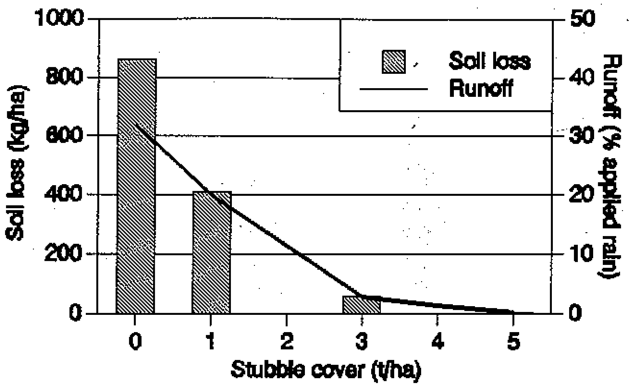

Figure 4 The effect of stubble cover on runoff and soil loss on a site with 5% slope.

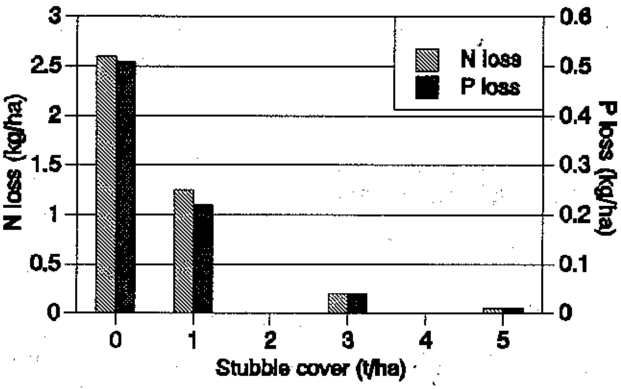

Figure 5 The effect of stubble cover on loss of N and P in the sediment removed by runoff water on a 5% slope.

On many Australian farms, stubble residues are grazed by sheep during the summer and autumn before sowing the next crop, as a means of stubble management and weed control. At one site, a high stocking rate was maintained for 25 days, prior to simulation at 3 levels of applied stubble cover. Overgrazing on this 5 - 7% slope damaged soil structure and loosened the surface soil, making it very susceptible to water erosion and high losses of soil. A second simulation run six days after the first was particularly erosive (Figure 6).

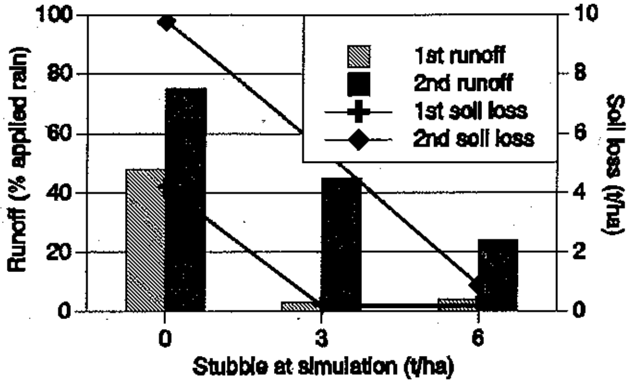

Figure 6 Runoff and soil loss from two simulated rainstorms on an overgrazed soil at three levels of applied stubble cover.

CONCLUSION

Conservation farming is an integrated system of land management that ensures the land can continue to support farming in the future without loss of productivity or viability. The system implies good land management practices, the key ones being sound rotations, reduced tillage and retention of crop and pasture residues. Where these practices are used, soil organic matter is maintained or increased, the soil surface is protected from raindrop impact and surface stability improves. Rainfall infiltration increases, while runoff and soil and nutrient losses are minimized. With the extra water and nutrients available for plant growth, crop production potential increases (4).

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QUANTIFICATION OF WATER AND SOLUTE TRANSPORT PROCESSES IN THE SOIL - METHODICAL ASPECTS

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ABSTRACT

The paper deals with aspects of the quantification of the water and solute transport in the field. The aim was to verify a simple method and a less extensive equipment to estimate the seepage rate and the mass flux of the solute transport out of the root zone in the field, based on hydrological measurements in the soil only. No knowlegde of meteorological data should be necessary.
Additional investigations in a soil column were carried out in the laboratory to verify the method. The results show the good correspondence between the measured and the calculated outflow volumes.

INTRODUCTION

The knowlegde on water and solute transport processes is important to protect the environmental resources. Intensive agricultural land use, the change of land using systems and industrial waste disposal are important sources for soil and ground water pollution. Controling water and solute transport in the soil requires knowlegde of their pathes and migration time to ground and surface waters.
Often mathematical models basing on the Richards equation are used in quantifying the water and solute transport. These models are complicated, and the results often are but limited practicable because of the high quantitity of required soil physical parameters. On the other hand, expensive measuring systems consisting of, a lot of tensiometers, soil water samplers and soil moisture probes are used for research purposes. The expenses for quantifying the infiltration rate out of the root zone are too great yet. Therefore a simple method to quantify the seepage was developed and tested.

MATERIALS AND METHODS

Theoretical basis

The water transport in the soil is described for steady-state conditions by Darcy's law

$$v = K * I \qquad (1)$$

with
- v - flux
- K - unsaturated hydraulic conductivity
- I - hydraulic gradient

Richards' equation connecting Darcy's law with the law of mass conservation for unsaturated soil conditions is mainly used to simulate transient water transport processes.

The following simplified theoretical basis was used to calculate the outflow volume and the solute transport out of the root zone.

Rain falls down and infiltrates into the soil. Immediately a change of storage, infiltration, evaporation and evapotranspiration processes occurs in the root zone, whereas in the zone not influenced by roots the water content and the tension are quite constant. The tension is nearly equal to the tension of field capacity in this zone, as long as the water flow is zero. Lowering the tension or increasing the water content in this zone is caused only by downward water movement, that means an infiltration situation.

Already Bodeman and Coleman, 1943 (acc. to (1)) described the course of the water content in the soil during an infiltration process (Fig. 1).

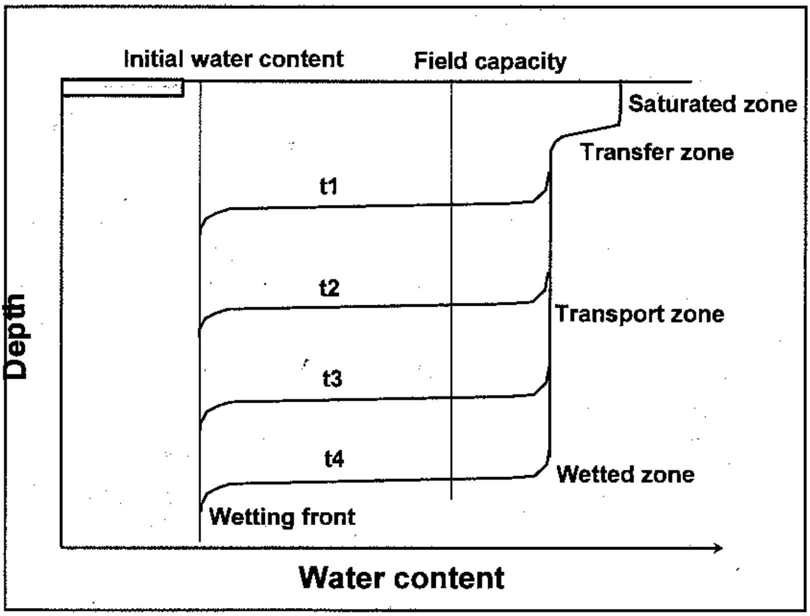

Figure 1 Schematic presentation of an infiltration process (Bodeman and Coleman, acc. to (1)

Water moves downward in the soil matrix, if the tension becomes lower than the tension at field capacity. The infiltration process occurs with a hydraulic gradient of approximately 1 in the transport zone. That means, there are nearly constant tension conditions during the infiltration time. Therefore it is possible to assume steady-state conditions for this time interval. The infiltration rate may be quantified from the following simplified form of equation 1:

RESULTS AND DISCUSSION

The soil hydrological functions, as the hydraulic conductivity and the water retention curve, are shown in Fig. 3. Quantifying the infiltration rate was based on this hydraulic conductivity function.

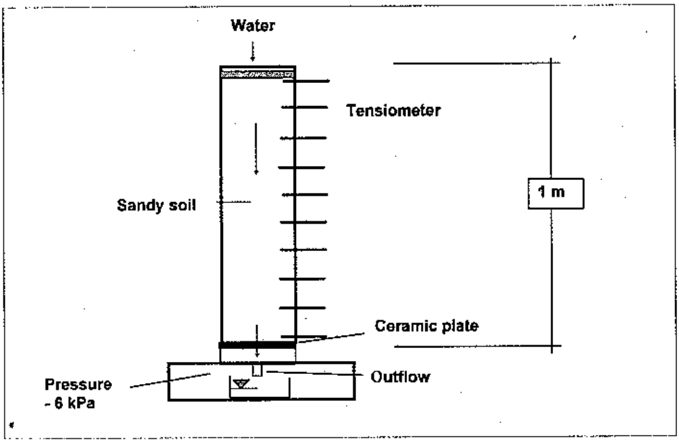

Figure 2 Schematic construction of the soil column

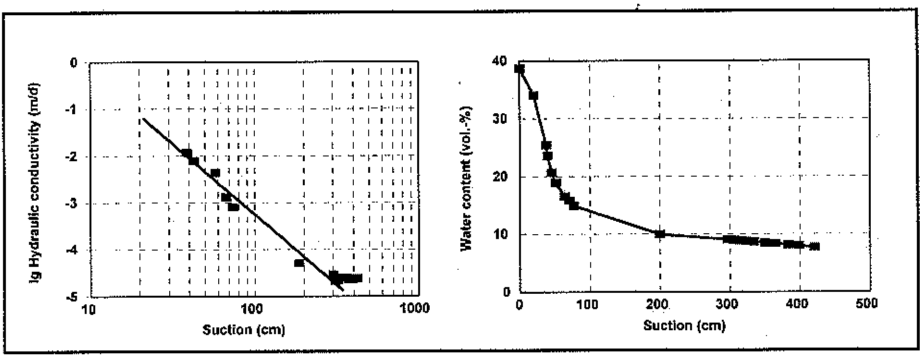

Figure 3 Unsaturated hydraulic conductivity and water retention functions of the sandy soil

Figure 4 presents the courses of tensions in the different depths after wetting. First the soil surface was saturated, and 40 minutes after sprinkling ponded conditions are evident. The soil water pressure becomes positive at a layer nearby the surface. Afterwards the course of the infiltration front along the depth is clearly recognizable. At 210 minutes after beginning it comes to the depth of 40 cm. The soil layer above already begins to drain. After 21 days the infiltration, transport and outflow procedure becomes extinct. The outflow rate is zero, and the change of the tension tends also to zero (Fig. 5).

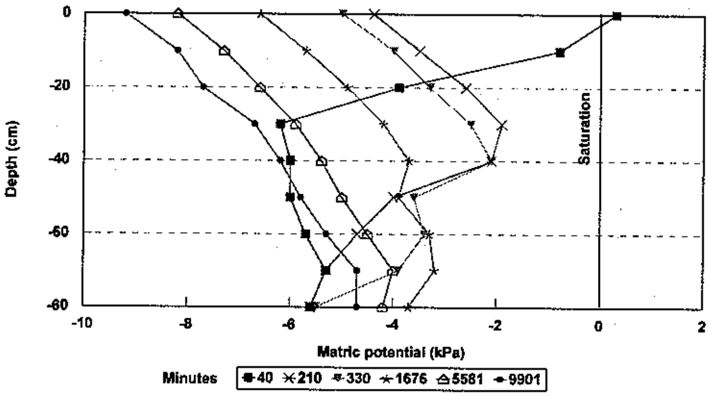

Figure 4 Courses of the tension values during the infiltration process

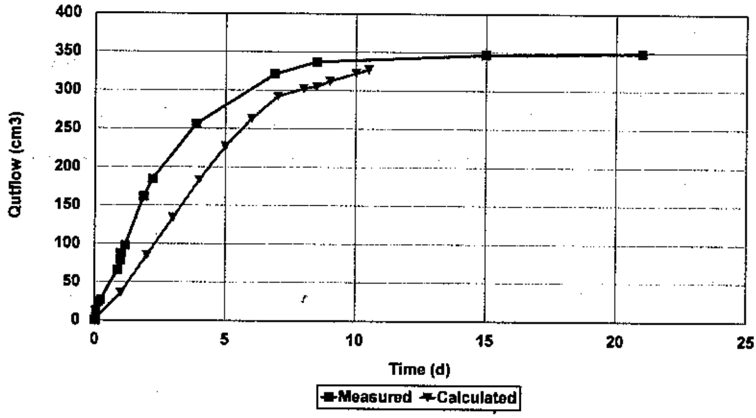

Figure 5 Comparison between the measured and the calculated outflow volume

The outflow function shown in Fig. 5 is of the exponential type. About 50 % of the total outflow volume drained already after two days, and more than 95 % of water drained during the first 8 days. The last 2 % (8 cm³) drained between the 15th and the 21st day.

The tensions measured at the depth of 80 cm were used to estimate the infiltration rate. Figure 6 gives an impression of the course of the tension at 80 cm below the surface during the experiment. The time of flow through that layer is clearly visible. It occurs mainly between the first and the eighth experimental day. The flow rates were calculated using the measured tensions and the values of the unsaturated hydraulic conductivity derived for intervals from the measured function. The calculated flow rates were summarized and compared with the measured outflow function (Fig. 5). The measured and the calculated final outflow volume correspond quite well.

$$v = K \qquad (2)$$

Concluding, to calculate the infiltration rate we need only knowledge of the hydraulic conductivity function in the suction range below the field capacity. Multiplying the hydraulic conductivity with the infiltration time we get the total outflow volume.

The solute transport may be quantified taking a soil water sample from the infiltrated water. This water has to be analysed in the laboratory, and we get the concentration of solutes. To estimate the mass of solutes leaving the root zone, multiplying the outflow volume with the concentration (Eq. 3, (2)) is possible:

$$m = c * V \qquad (3)$$

with: m - mass of solutes
c - concentration
V - water volume

The main tasks in estimating the water volume and the mass of solutes leaving the root zone are:

1. Quantifying the unsaturated hydraulic conductivity function in the tension range lower than field capacity in the soil layer below the root zone.
2. Measuring the time course of the tension and/or the water content to determine the time of flow through that layer. The measuring value mostly sensitive describing the process has to he used. It is dependent on the soil conditions, especially the course of the water retention curve up to field capacity.

Soil column experiments

Soil column experiments were carried out to verify the methodical basis of estimating the infiltration rate out of the root zone.

The column (a pipe with a diameter of 10,5 cm and a height of 100 cm) was filled with medium sand. Soil samples (250 cm³) were taken during the filling process to quantify the unsaturated hydraulic conductivity and the water retention curve. This was done using the evaporation method (3).

Afterwards, the column was sealed at the hottom with a ceramic plate, saturated to field capacity with a suction of 6 kPa at the bottom, and tensiometers were built in at distances of 10 cm (Fig. 2). The experiment was started when steady-state conditions appeared, that means the outflow had to be zero over a longer time. The soil column was sprinkled at the surface with 40 mm of water, and the courses of tensions in the different depths as well as the outflow rate were measured. The soil surface was covered with a plastics foil during the experiment. After the experiment the measured outflow rates were compared with the calculated infiltration rates at a selected depth of 80 cm basing on the theoretical foundation described in the chapter before. To do so, the measured hydraulic conductivity functions were used.

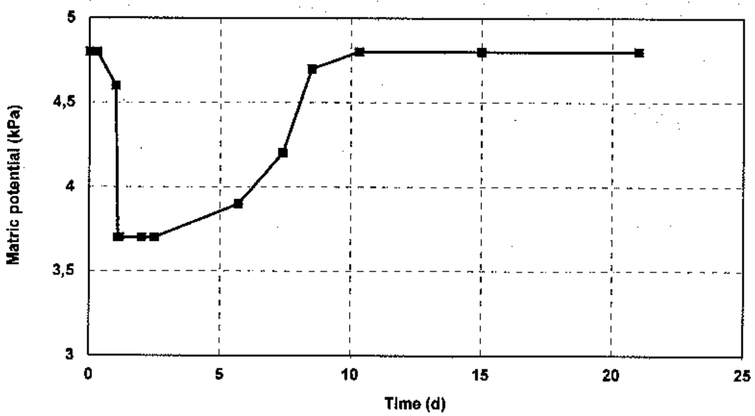

Figure 6 Course of the tension at a depth of 80 cm

The results are comparable with the measured ones. The differences in the course and in the final values may be eliminated by fitting the hydraulic conductivity function to the process. This was, however, not done in that experiment.

The required measuring accuracy to quantify the transport time is high. The suction has to be measured with an accuracy of approximately 0.1 kPa. The accuracy of the quantified hydraulic conductivity function is also high, especially in the lower range of suction.

CONCLUSION

The simple method to estimate the infiltration rate based on soil hydrological measurements was tested and verified in a soil column experiment. In future it will be necessary to carry out field experiments estimating the infiltration process out of the root zone. The applicability of this simple method and equipment has to be tested. Measuring the soil hydrological parameters - tension and soil water content - and taking soil water samples in only one layer below the root zone should allow to estimate the infiltration process. These experiments are in preparation.

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MINIMISING SOIL EROSION AND RUNOFF IN TRACTOR WHEELINGS

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ABSTRACT

Exploratory experiments were conducted to identify simple low cost techniques capable of reducing runoff and soil erosion in tractor wheelings. A technique based on anchoring chopped straw in the wheeling shows considerable promise for substantially reducing soil loss and runoff.

INTRODUCTION

Tractor wheel ruts, tramlines and traffic lanes often prove to be sites of accelerated soil erosion and runoff when aligned with slopes on erodible soils. These problems arise largely due to wheel compaction reducing soil infiltration rate and to the rut section concentrating runoff water in its centre. Erosion and runoff can occur during rainfall and in some situations with overhead irrigation. Environmental concern is currently increasing in the United Kingdom with regard to soil loss from these tramline systems, necessitating an early solution.

Farmer practice in some local areas is to loosen the rut tramline area before potential erosion periods in winter, to increase water infiltration rate. Although this practice helps reduce runoff it unfortunately induces increased wheel sinkage during subsequent traffic passes in the same location and delays access and hence operations during wet periods. This paper describes the results of exploratory trials to assess the effectiveness of simple low cost techniques, which avoid loosening the compacted zone, in minimising these problems.

Three approaches were considered:
A) anchoring a straw mulch in the rut to reduce soil detachment and runoff velocity,
B) changing the wheel rut section to induce outward lateral water flow into loosened areas at the sides of the rut,
C) a combination of A and B.

MATERIALS AND METHODS

The straw mulch treatment was installed at seed drilling time, by spreading chopped wheat straw ahead of the tractor wheels establishing the tramlines. The tyre treads pressed the straw into the loose soil, thereby achieving straw anchorage. Two tractor passes were made for incorpotation and the straw was anchored at depths between 2 and 14 mm. The mean straw chop length was 170 mm, it was applied at a rate of 0.5 kg m^{-2} and this provided about an 80% straw cover in tramlines.

A tramline drainage implement (1), see Fig. 1, was used to modify the wheel rut profile, to encourage lateral movement of runoff water out of the wheeling. The profile change aimed for is illustrated in Fig. 2, where the centre section of the rut is raised and domed slightly to shed water outwards and the extremities of the rut loosened, to alleviate any compaction which may inhibit lateral water flow. The angled tines alleviate compaction in the corners of the rut and the soil they bring to the surface is transferred into the centre of the rut by the angled blades. After this operation the soil in the rut was compacted by one further tractor pass.

The combined straw mulch/profile modification treatment was installed by first anchoring the straw, then modifying the rut with the tines, which deposited soil on top of the straw. One further pass with a tractor was made before water application. A wheel rut without straw was used as the control treatment.

The test soil was an erodible sandy loam, with a mechanical analysis of 14% coarse sand, 55% fine sand, 19% silt and 12% clay. The tramline treatments were installed on a 5.6% slope with 4 replications, and the water runoff and soil loss from a 30 m length of tramline was collected in a metal trough for analysis. Tramline profiles, surface layer soil densities and shear strengths, and water flow paths were recorded.

During the period of the experiment four significant runoff events occurred, two initiated by natural rainfall and the others by overhead sprinkler irrigation.

RESULTS AND DISCUSSION

Tramline profiles and conditions

Representative cross sections of the tramline profiles are presented in Fig. 3. The profiles of the control and straw mulch tramlines, Fig. 3a, took the common dished form, sloping towards the centre. The tyre tread pattern was readily discernible, angled at 15^{o} to the side of the rut. Maximum rut depth was approximately 60 mm.

The modified tramline drainer profiles Fig. 3b, had a much flatter base, the following tractor pass tending to level out the central cambered area. Again the tread pattern was present, but the soil between the tread depressions was less well compacted and weaker, than the equivalent in the control and straw mulched treatments. Density values of 1.72 and 1.62 tm^{2} and shear vane readings of 12.5 and 6.3 kpa were recorded in this inter-tread area, in the control and modified profiles respectively.

Due to the presence of some side slope on the experimental field, some sections in a number of the modified tramline profiles, were inclined to the horizontal see Fig. 3c. This, together with differences in the degree of central camber and flatness, introduced considerable profile variation in these treatments.

Fig. 1 Tramline drainage implement

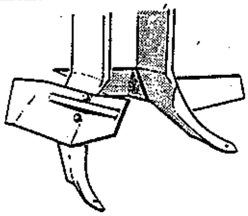


Fig. 2 Initial (a) and modified (b) rut profiles

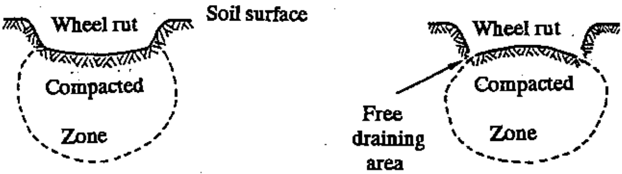
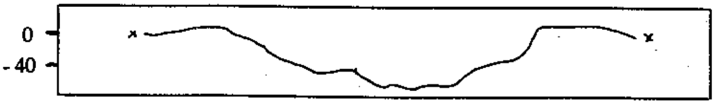
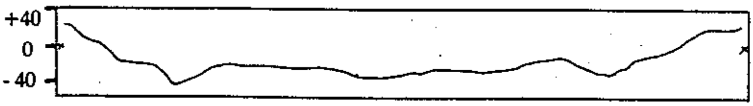


Fig. 3 Rut profiles

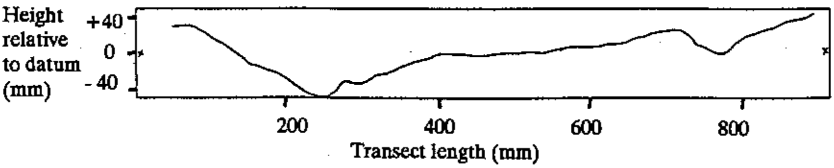
a. Control and straw mulch section



b. Modified rut section



c. Modified rut section on side slope



Water runoff and soil loss

Tables 1 and 2 record the soil loss and runoff quantities from the different replicates and treatments arising from the four runoff events. Details of the application quantities and intensities are presented in Table 3. The extent of runoff and soil loss/unit of water input decreased markedly after the first runoff event. All three treatments reduced substantially the extent of soil loss and runoff compared with the standard control, but their reliability differed. By far the most consistent was the anchored straw mulch treatment, which proved particularly effective in reducing soil loss and runoff. The performances of the modified profiles, both with and without straw were erratic, some tramlines exhibiting zero soil loss or runoff, whilst others approached and occasionally exceeded the standard control.

The reasons for the variable performance of the modified profiles were, the lack of a consistent camber in the bottom of the tramlines and the more readily erodible soil between the tyre tread indentations. Where a satisfactory camber was achieved or a regular cross slope prevailed, control over soil loss and runoff was very effective. The flattish cross sections in the rut bottom were not so effective, although initially in combination with the tyre tread depressions, they were successful in diverting water laterally. With time, however, the less compacted soil between the tread depressions started to erode forming small channels, some of which concentrated water flow down, rather than across the slope, hence increasing runoff and soil loss.

More effective compaction of the soil between the tread depressions in the modified tramline treatments would reduce the breakdown risk and this compaction could be more effectively accomplished with a smoother tyre. Nevertheless, the possibility of the cambered or flattened profiles in the rut base becoming bowl shaped with subsequent traffic is very high, increasing the susceptibility to erosion. In view of this and on the evidence of the serious breakdown in erosion control which occured on some of the replicates, the modified tranline approach cannot be recommended in its present form.

CONCLUSIONS

Runoff and soil erosion in tractor wheelings and tramlines can be a serious problem on sloping erodible soils. A simple technique of anchoring chopped straw into the wheeling or tramline has proved effective in initial studies, in substantially reducing soil loss and runoff. The straw is dropped ahead of the tramline forming wheel and anchored by the tyre treads as they are driven across the straw.

Use of tramline draining equipment to alter the rut profile and encourage lateral rather than longitudinal water flow from the tramline, proved much less reliable than the straw mulch technique. This was due to the inability to consistently achieve a cambered profile in the base of the rut. This technique has therefore, much less potential as an erosion control measure than the straw mulch.

Table 1 Soil loss

Treatment	Replicate	Soil loss (g) during different runoff events			
		1	2	3	4
Control	1	113	11	0	18
	2	675	14	23	12
	3	70	12	0	12
	4	24	23	28	4
Straw mulch	1	16	2	3	2
	2	6	2	0	4
	3	12	0	0	0
	4	0	0	0	0
Modified tramline	1	0	7	0	0
	2	85	29	28	12
	3	0	0	0	0
	4	0	0	0	0
Modified tramline + straw	1	70	16	19	3
	2	16	0	0	0
	3	33	3	0	3
	4	4	4	0	0

Table 2 Runoff

Treatments	Replicate	Runoff quantity (l) during different runoff events			
		1	2	3	4
Control	1	7.1	1.6	0	0.2
	2	6.2	2.0	0.8	2.6
	3	4.8	2.3	0	0.2
	4	5.6	3.0	6.0	0.1
Straw mulch	1	4.8	0.4	0.2	0.4
	2	1.3	0.3	0	0.1
	3	2.9	0	0	0
	4	0.1	0.1	0	0
Modified tramline	1	0	0.2	0	0
	2	5.4	3.1	8.3	0.3
	3	0	0	0	0
	4	0	0	0	0
Modified tramline + straw	1	3.5	1.5	0.9	0.3
	2	0.1	0	0	0
	3	0.1	0.1	0	0.1
	4	0.1	0.4	0	0

Table 3 Application quantities and intensities

Event	Application Quantity (mm)	Average intensity (mm h^{-1})
1 (Rain)	37	4
2 (Irrig)	25	25
3 (Irrig)	25	25
4 (Rain)	6	4

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SOIL CHEMICAL PROPERTIES OF AN ERODED HILLSLOPE

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ABSTRACT

Identifying spatial patterns of soil properties can provide useful information for making management decisions. Objectives of the study were to assess the spatial distribution of exchangeable Ca^{+2}, Mg^{+2}, Na^{+} and K^{+} on an eroded hillslope and to equate distribution patterns to erosion rates based on ^{137}Cs analysis. Soil samples were obtained from a 6.5 ha cultivated field at a grid spacing of 30.5 m. Descriptive statistics were used to describe the overall distribution and variability of properties. Semivariograms were developed to determine the spatial dependence of soil properties. At the surface 0- to 10- cm depth, Ca^{+2} and Na^{+} varied isotropically with spherical semivariograms, Mg^{+2} varied isotropically with an exponential semivariogram and K^{+} varied isotropically with a linear semivariogram. Ranges of the semivariograms were 233, 146, 156 and >177 m for Ca^{+2}, Mg^{+2}, Na^{+}, and K^{+}, respectively. Block kriging was used to interpolate properties at unsampled locations using 9 to 16 nearby points. Distribution patterns of Ca^{+2} and Mg^{+2} were low on less eroded parts of the field where higher amounts of rainfall infiltrate soil, washing these salts to deeper soil layers as compared to severely eroded parts of the field.

INTRODUCTION

The use of geostatistical methods in soil science has gained much importance in recent years. Research on spatial variability of several soil properties showed that sodium content varied isotropically with a linear semivariogram, stoniness varied anisotropically with a linear semivariogram, and the thickness of cover loam varied isotropically, but with a spherical semivariogram (1). Spatial distribution of soil physical properties including 0.1 and 15 bar water content, available water, surface area, particle size distribution, bulk density and moisture content was examined on a Typic Torrifluvent (2). The ranges of semivariograms for soil chemical properties such as pH, Ca, Mg, K, Si and P sorbed at 0.02 mg P/L were reported as 32 to 42 km on the island of Hawaii (3).

Objectives of the study were to assess the spatial distribution of exchangeable Ca^{+2}, Mg^{+2}, Na^{+} and K^{+} on an eroded hillslope and to equate distribution patterns to erosion rates based on ^{137}Cs analysis.

MATERIALS AND METHODS

This study was conducted on a 6.5 ha cultivated field in western Cass County, Nebraska, USA (96°24'W and 40°59'N). The soil was a Sharpsburg silty clay loam (fine, montmorillonitic, mesic Typic Argiudoll) with slope gradients ranging from 0 to 9%. Soil cores, 40 cm deep and 6.4 cm diameter, were obtained at a grid spacing of 30.5 m. Soil samples were sectioned into 10 cm increments and analyzed for exchangeable Ca^{+2}, Mg^{+2}, Na^{+} and K^{+} using NH_4OAc method (4).

Descriptive statistics were used to describe the overall variability within the field. Semivariograms were developed to determine the spatial dependence of soil properties using the following equation (5):

$$\gamma^{*}(h) = \frac{1}{2N(h)} \sum [Z(x_i) - Z(x_i + h)]^2$$

where

$\gamma^{*}(h)$ = semivariance,
$N(h)$ = the number of experimental pairs separated by a distance h,
$Z(x_i)$ = measured sample value at point i, and
$Z(x_i+h)$ = measured sample value at point i+h.

Directional experimental semivariograms were calculated at angles of 0° (N to S), 45° (NE to SW), 90° (E to W) and 135° (SE to NW) to test the presence or absence of anisotropic spatial dependence. Block kriging was used to predict soil properties at 3.8 m intervals nsing 9-16 maximum nearby points by considering the ranges of experimental semivariograms.

Semivariograms and kriging maps were developed using GS^{+} geostatistical software (6).

RESULTS AND DISCUSSION

Descriptive Statistics

Variation in exchangeable Ca^{+2} and Mg^{+2} was greater in the surface 20 cm tban in the deeper soil depths (Table 1). Exchangeable Na^{+} and K^{+}, however, had a relatively constant variability with soil depth. The means of exchangeable Ca^{+2}, Mg^{+2}, and Na^{+} were lowest at the surface 0- to 10- cm and increased with depth as a result of leaching. Conversely, the mean of exchangeable K^{+} was greatest at the surface and decreased with depth. This may be due to fertilizer applications and maintenance of surface residue.

Table 1. Summary statistics of some soil chemical properties of an eroded hillslope.

Soil Property	Depth cm	Min.	Max.	Mean	SD†	CV‡ %
	0-10	10.4	17.3	13.74	1.64	12
Ca^{+2}	10-20	11.5	18.8	15.5	1.74	11.2
$cmol_c\ kg^{-1}$	20-30	13.4	18.7	16.93	1.03	6.1
	30-40	14.3	19.5	17.6	0.99	5.6
	0-10	3.9	7.7	5.97	0.92	15.4
Mg^{+2}	10-20	4.43	10.6	7.29	1.31	18
$cmol_c\ kg^{-1}$	20-30	5.34	11.3	8.39	1.11	13.2
	30-40	5.28	12.2	8.89	1.15	12.9
	0-10	0.087	0.314	0.178	0.062	34.8
Na^{+}	10-20	0.114	0.416	0.224	0.074	33.1
$cmol_c\ kg^{-1}$	20-30	0.134	0.653	0.281	0.095	33.9
	30-40	tr	0.816	0.322	0.126	39.2
	0-10	0.839	1.76	1.16	0.2	17.2
K^{+}	10-20	0.578	1.45	0.868	0.173	19.9
$cmol_c\ kg^{-1}$	20-30	0.526	1.49	0.761	0.151	19.8
	30-40	0.536	1.21	0.676	0.096	14.2

† = standard deviation; ‡ = coefficient of variation; tr = trace.

Geostatistical Analyses

Experimental semivariograms computed in different directions did not show significant differences. Therefore, the spatial distribution of all soil properties was considered isotropic, and a single semivariogram analysis was performed. Spherical or linear models generally provided the best-fit for most chemical properties at four different soil depths (Table 2). The best-fit semivariogram models were chosen using least squares among five different commonly used models; linear, linear with sill, spherical, exponential and Gaussian.

One of the most important use of semivariograms is to define the zone of maximum variability (range) of a property. Samples separated by a distance less than the range are spatially correlated. The ranges of semivariograms at the 0- to 10- cm were greater than for the deeper soil depths, and were 233, 146, 156 and >177¶ m for Ca^{+2}, Mg^{+2}, Na^{+}, and K^{+}, respectively. In all cases, the nugget variances, explained as a percent of sill variance, were less than 50%, which indicated that spatial variability explained a greater portion of the variation in soil properties.

¶ The range for the linear semivariogram models was assumed to be greater than 50% of the maximum lag which was 355 m.

Table 2. The best-fit experimental isotropic semivariogram models and parameters for some soil chemical properties.

Soil Property	Depth cm	Model	Range m	Nugget %	r^2
	0-10	Spherical	233	10	0.99
Ca^{+2}	10-20	Spherical	72	48.8	0.88
$cmol_c\ kg^{-1}$	20-30	Spherical	81	34.5	0.72
	30-40	Spherical	149	15.8	0.95
	0-10	Exponential	146	0.1	0.93
Mg^{+2}	10-20	Spherical	56	2.5	0.88
$cmol_c\ kg^{-1}$	20-30	Spherical	66	3.2	0.83
	30-40	Exponential	107	18.4	0.99
	0-10	Spherical	156	43.9	0.94
Na^{+}	10-20	Linear	-	-	0.87
$cmol_c\ kg^{-1}$	20-30	Linear	-	-	0.70
	30-40	Linear	-	-	0.66
	0-10	Linear	-	-	0.96
K^{+}	10-20	Linear	-	-	0.92
$cmol_c\ kg^{-1}$	20-30	Linear	-	-	0.80
	30-40	Linear	-	-	0.57

The distribution maps of soil chemical properties at the surface 0- to 10- cm from block kriging are presented in Figure 1. High concentrations of exchangeable Ca^{+2}, and Mg^{+2} were found primarily in the northwestern part of the field where the slope gradient is relatively high whereas exchangeable Na^{+} and K^{+} concentrated in the northern and eastern part of the study area.

Patterns of spatial variability of soil chemical properties at the upper soil depths had close agreement with erosion patterns derived from geostatistical analysis of ^{137}Cs activity (7). The non-shaded areas on the distribution map in Figure 2 show the most severely eroded parts of the field, and the dark colored areas indicate the areas with least erosion. Comparison of distribution maps of soil properties with erosion patterns showed that exchangeable Ca^{+2} and Mg^{+2} were low on less eroded parts of the field where higher amount of rainfall infiltrate soil, likely washing the salts to deeper soil layers as compared to severely eroded parts of the field. Although exchangeable Na^{+} was generally low on less eroded areas, the agreement between distribution patterns was not as clearly evident as for Ca^{+2} and Mg^{+2}. Exchangeable K^{+}, however, did not show clear similarities with erosion patterns. The well-defined correlation between spatial distribution patterns of Ca^{+2} and Mg^{+2} and annual erosion rates for the upper soil layers was not present for the deeper soil layers.

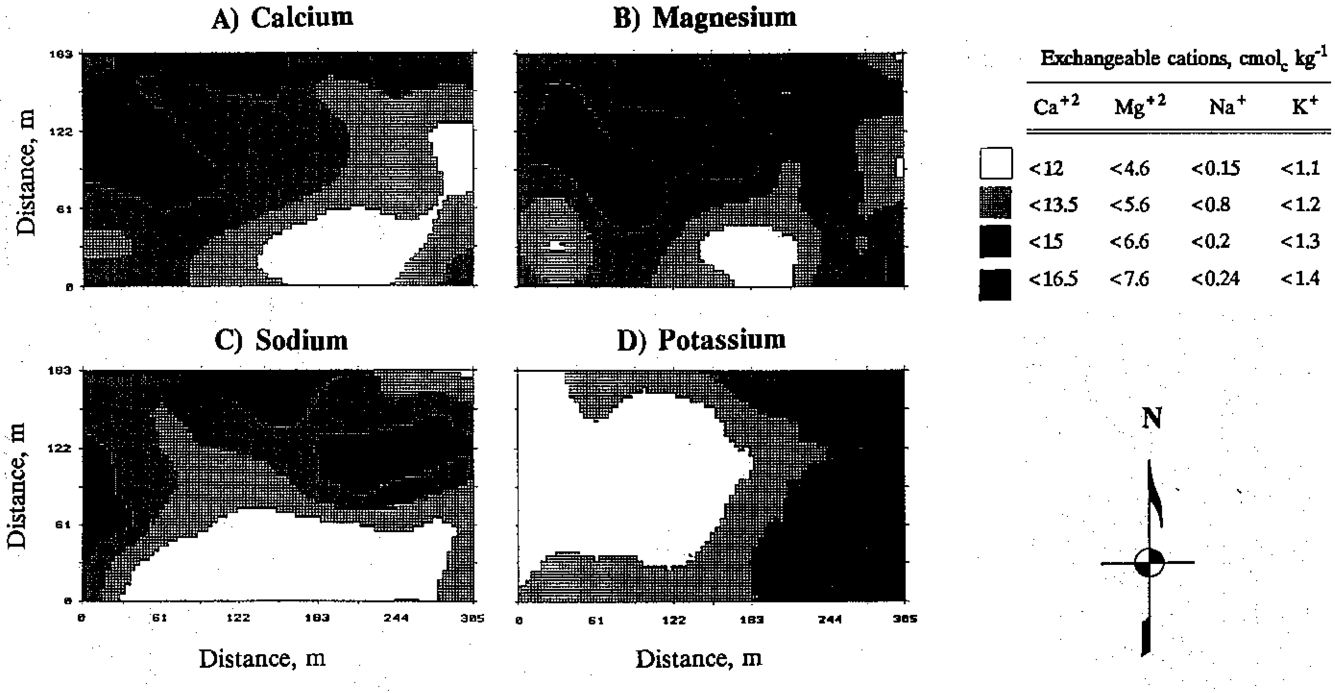

Figure 1. Spatial distribution patterns of soil chemical properties at the surface 0- to 10- cm from block kriging.

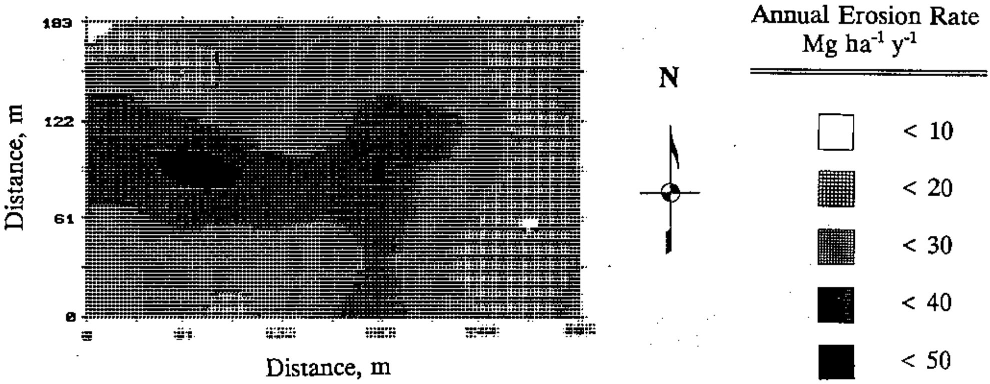

Figure 2. Spatial pattern of erosion rates from block kriging estimates of ^{137}Cs activity.

CONCLUSIONS

Exchangeable K^+ was greatest at 0- to 10- cm, and decreased with depth. Conversely, exchangeable Ca^{+2}, Mg^{+2} and Na^+ increased with depth likely due to leaching.

Calcium and Mg^{+2} concentrations were low on less eroded parts of the field where higher amounts of rainfall infiltrate soil, likely washing these salts to deeper soil layers as compared to severely eroded parts of the field. Exchangeable Na^+ and K^+, however, did not show clear similarities with erosion patterns.

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Tillage technique for effective soil erosion control in Kenya: Evaluation of alternative fanya juu terrace designs.

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Abstract

The "Fanya Juu" terrace, a form of developed bench terrace, is the most widely used conservation structure on small scale farms in different agro - climatic zones of Kenya. The term "Fanya Juu" is a Swahili language expression for " make it up" which essentially refers to the construction of the embankment upslope. The construction of this terrace is through labour intensive methods and involves digging a channel on the contour and throwing the soil upslope to form an embankment which is often stabilized with grass. The conventional terrace design consists of an embankment, a berm or ledge, and a channel. Fanya juu terraces have been used in Kenya for many years and are meant to impound and conserve runoff water, soil and nutrients on the upslope side of their embankments to sustain the crop yield potential of land. Its applicability to area specific conditions depends on factors such as slope limits, labour availability, soil erodibility, rainfall erosivity and soil depth. Its rate of development into a bench terrace depends on the extent and frequency of cultivation.

This paper evaluates alternative fanya juu terrace designs so as to eliminate any wastage of land after the terraces have been constructed. Alternative Fanya juu terrace designs whilst primarily aimed at structural effectiveness in erosion control, should also ensure that borrow areas (channels) for embankment soil are limited to the top soil. This restriction of the depth of cut provides for immediate utilization of the shallow channel for crop production and hence minimizing any wastage of land. The shallow depth of cut also minimizes any significant changes in soil fertility.

Introduction.

The majority of Kenya's rural population comprises of small scale farmers with farm sizes averaging about 1.4 hectares each. The area occupied by small scale farms is more than twice the area occupied by large scale farms. About 40% of the small scale farms contribute to the country's commercial agricultural production. The other 60% of these small scale farms are wholly engaged in subsistence agriculture.

The scope for expanding cultivated land and maintaining soil productivity in high/medium rainfall areas (occupying about 20% of the total area of Kenya) is rapidly diminishing due to population pressure and on going fragmentation of land. Population pressure and subsequent overutilization of land have significantly contributed to the deforestation, overgrazing and cultivation on very steep slopes that is quite evident in most high/medium rainfall areas of Kenya. Thus in order to meet the food requirements of this ever increasing population, this land must be intensively cultivated and conserved to sustain its agricultural productivity. At the same time more of the marginal land (occupying about 72% of Kenya's total land area) must be brought into agricultural production.

The most effective means of sustaining soil productivity on small scale farms is by introducing appropriate tillage practices that would conserve soil and water. The tillage practices widely used in these areas are structural and include channel terraces, excavated and developed bench terraces (i.e fanya juu terraces). The "Fanya Juu" terrace, a form of developed bench terrace is the most common structure on small scale farms and is constructed using labour intensive methods. The construction of this terrace involves digging a trench or channel on the contour and throwing the soil uphill to form an embankment which is thereafter stabilized with grass. Fanya juu terraces have been used in Kenya for many years and are meant to impound runoff water, soil and nutrients on the upslope side of their embankments to sustain crop yield potential of the land.

Soil moisture conservation is a priority in marginal rainfall areas of Kenya and previous studies on this have showed that a 5% increase in soil moisture could increase maize yields by 15% (Moore, 1979). This soil moisture increase is easily attained from fanya juu terraces. Soil conservation surveys conducted in two high/medium rainfall areas of Kenya namely: Kiambu (Mati, 1984) and Muranga (Ngugi and Bradley, 1986), have shown that fanya juu terraces account for more than 50% of the conservation structures constructed on small scale farms. Fanya juu terraces are also popular in semi arid areas of Kenya (e.g. Machakos and Kitui) where some remarkable increases in farm crop yields have been noted. The choice of fanya juu terraces by farmers in different agro climatic zones of Kenya, is influenced by many factors such as size of landholding, slope of land, labour availability, rainfall erosivity, soil erodibility, soil depth and the period taken for the structures to develop into bench terraces and hence reduce the slope of the land. Small scale farmers in all parts of the country have realized that conservation of the limited land resource for sustained agricultural productivity is inevitable. Hence they have intensified their conservation farming practices with a view to maximizing the agricultural productivity of all available cultivable land. These efforts require some re-evaluation/assessment of present conservation strategies/designs and where possible modifying existing conservation measures to meet this need for sustained soil productivity and increased crop yield per unit area.

The conventional design of fanya juu terraces consists of a cross sectional area made up of an embankment to impound runoff water, soil and nutrients ; a channel to take care of unexpected embankment failure due to overtopping of runoff water and a berm or ledge to prevent embankment soil from sliding back into the channel. This design requires some modification to avoid the wastage of land (currently occupied by the channel) and thus provide the farmer with more land to grow crops on. Many questions have been raised about the rationale of keeping a channel (whose only function is to serve as a precautionary measure against terrace embankment failure due to flood damage) and the grading of fanya juu terraces (since the embankment is supposed to impound the runoff and not to dispose of it). These questions have arisen due to the lack of adequate research to justify the technical performance and sustainability of current fanya juu terraces. Certainly, this current conventional terrace design has failed to incorporate the farmers priority of maximum utilization of all available cultivable land for agricultural production. It is therefore imperative that other designs be developed to meet the expectations of small scale farmers.

This study evaluates alternative fanya juu terrace designs that would eliminate wastage of land and also attempts to examine the effectiveness, sustainability and application of the terrace to area specific conditions.

Design considerations

Fanya juu terrace design is based on an assumption that terraces should effectively retain or discharge the heaviest runoff expected during a 10 year return period (Thomas et al.,1981). This assumption is also partially based on economics in that structures with return periods of more than 10 years would be too massive and hence costly to construct and maintain. From studies conducted on terrace design in Kenya (Thomas et al.,1981) a 1 hour storm with a 10 year return period would generally lead to the greatest runoff and should be used for terrace design. Measurements of minimum infiltration rates of a Machakos Luvisol (Alfisol) using a rainfall simulator, gave the maximum depth of runoff expected from this 1 hour storm as 45 mm. This figure was based on a minimum infiltration rate of 10 mm/hr for the Luvisol (Alfisol). Terrace design of fanya juus is based on rainfall intensity, soil and slope of the land. These factors influence surface runoff rates and hence the expected embankment stability and storage capacity. The cross sectional area above the embankment required to retain all surface runoff is a function of terrace spacing or contributing catchment area and the expected surface runoff.

Terrace Channel Depth

To sustain soil fertility, the depth of cut of fanya juu channels should be limited to the top soil layer. Studies on the nutrient status of some Kenyan soils have shown that there are some significant decreases in phosphorus and organic carbon with soil depth.

Mwonga et al (1986) found that there were significant changes in organic carbon of 60% (for Luvisols), 40% (for Andosols) and 50% (for nitisols) within a soil depth of 50 cm. Similar trends have been noted for Nitisols where upto a depth of 100 cm, phosphorus and organic carbon decreased by 75% and 85% respectively (Ronoh, 1987).

Embankment Stability.

The strength and effectiveness of a fanya juu terrace depends on the ability of embankment soil to withstand the pressure exerted by sediment and runoff water. The stability of the terrace embankment is directly influenced by soil structure and the angle of friction (repose) between the embankment and the slip or ground surface. It has been established that gravitational forces due to the weight of embankment soil begin to move the soil downslope when the angle of friction is equal to or greater than 30° (58%). Where this angle of friction is not exceeded, the stability of the terrace embankment has been strengthened by planting various perennial grass species.

Embankment Storage Area

Given an embankment angle (σ), a field slope angle (ϕ) and the depth of storage (d), the cross sectional area (A) can be computed from the formula:

$$A = 1/2\ d^2(\cot\sigma + \cot\phi)$$

Where

A = Terrace cross sectional storage area (m)
d = Depth of storage (m)
σ = Embankment angle (°)
ϕ = Field slope angle (°)

In most terrace construction works, the embankment angle σ, lies between 30° and 45°. The field slope angle varies with land topography. The maximum depth of storage (d) can be computed with the formula:

$$d = \sqrt{} 2 A / (\cot\sigma + \cot\phi)$$

In practice, a freeboard of about 10 cm and an embankment settlement allowance of about 25% of d should be included to obtain the maximum design depth of the terrace.

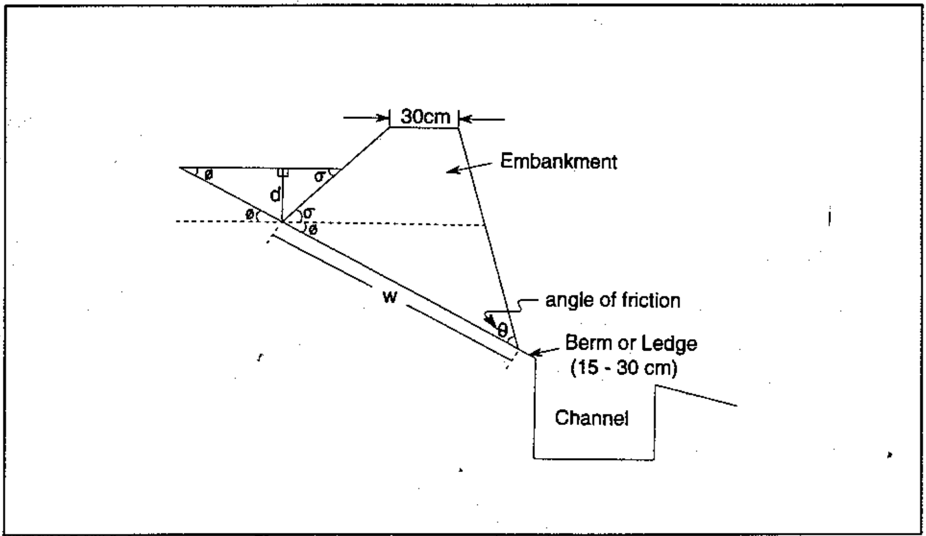


Fig. 1. Fanya juu terrace profile.

Thomas et al., (1981) developed a nomograph (see fig.2) for estimating the depth of storage (d). Data required to estimate this depth of embankment storage is the maximum one hour rainfall in mm for the chosen return period, minimum infiltration rate(mm), terrace spacing (m) and the slope of the land (%).

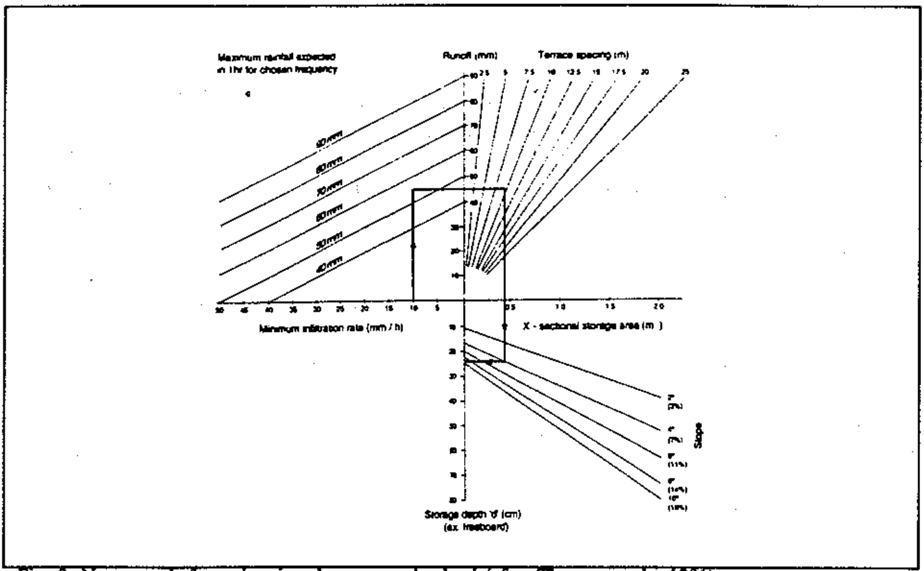
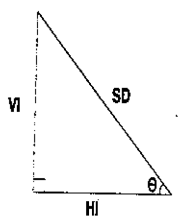


Fig. 2. Nomograph for estimating the storage depth, d (after Thomas et al., 1981)

Embankment Spacing.

Terrace spacing is computed as slope distance (SD) from established values of vertical and horizontal intervals (VI and HI). VI and HI can be determined if the slope of the land is known in percentage. There is no significant difference between SD and HI. Thus HI is often used as terrace spacing. The basic formulae used to determine terrace spacing in Kenya are:



$$VI\,(m) = \left[\frac{\%S}{a} + b\right] 0.3 + 25\%$$

$$HI\,(m) = \frac{VI \times 100}{\%S}$$

$$SD = \left[(VI)^2 + (HI)^2\right]^{1/2}$$

Where;

VI = Vertical interval, m
HI = Horizontal interval, m
S = Slope of the land, %
a = Rainfall factor
b = Erodibility factor
SD = Slope distance, m
± 25% = Adjustment that compensates for soil and crop management variabilities.

For Kenyan conditions the rainfall factor, a varies from 1.5 for low rainfall to 4 for high rainfall areas.

Similarly, the erodiblity factor, b ranges from 1 for low erodibility to 3 for high erodibility. Often a rainfall factor of 4 and an erodibility factor of 2 are used to compute vertical interval under Kenyan conditions.

Terrace designs

The conventional terrace design (see fig. 4) consists of a cross sectional area made up of an embankment, a berm or ledge and a channel. Most embankments have widths varying between 1.0m and 1.5m. The berm or ledge has a width of 0.15m to 0.3m and the channel depths vary from 0.6m to 1.0m with a top width of about 0.6m. Taking the areas of terrace ground cover per unit length of embankment, berm and channel, the area occupied by the channel expressed as a percentage of the total terrace unit area is approximately 36%. Besides occupying such a large surface area, the channel depth of 0.6m to 1.0m is beyond most top soil layers and more into the subsoil horizons. Studies on nutrient availability of some Kenyan soils showed marked trends of phosphorus and carbon decrease with depth (Ronoh, 1987; Mwonga et al., 1986). Hence the subsoils used to form embankments under such soil conditions, have low phosphorus and organic matter contents. The channel with these nutrient deficiencies cannot sustain any good crop growth. Under normal farming practices, channels are used as borrow areas for embankment soil and thereafter left unutilized in many instances. Most small scale farmers are of the view that the unproductive channel could be done away with and the terrace unit area reduced to the minimum in order to utilize all available cultivable land for maximum crop production.

The modified terrace design (see fig. 4) has attempted to eliminate most of the deficiencies of the conventional design. The unproductive channel is replaced by a much wider borrow area with the most minimum depth of cut.The depth of cut should be within the top soil layer and the borrow area put into production immediately after the terrace is constructed. Due to the shallow depth of cut, any nutrient deficiencies within the embankment soil would be unlikely unless inherent in the top soil. The new design also hastens the rate of development of a bench terrace.

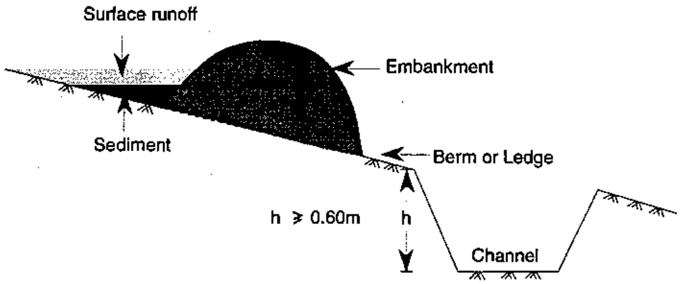


Fig. 3. Conventional fanya juu terrace design.

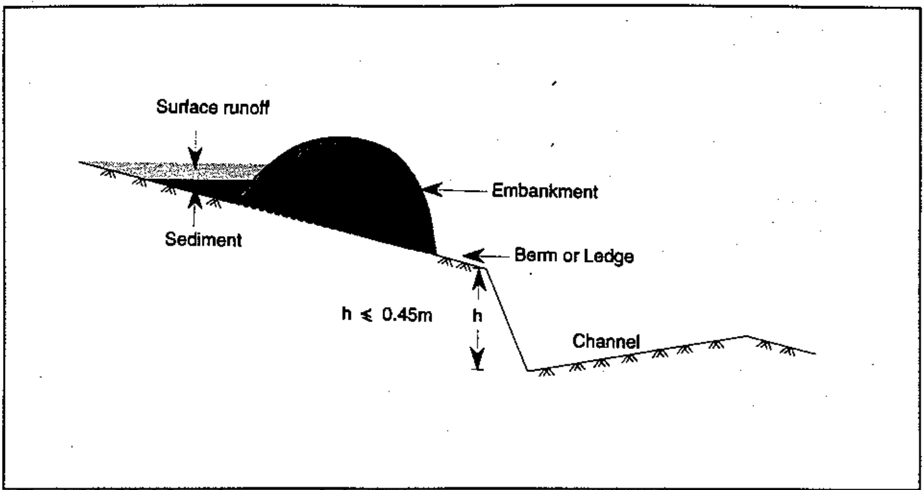


Fig. 4. Modified fanya juu terrace design.

Discussion.

Fanya juu terraces are the most widely used conservation structures on small scale farms in Kenya. The choice of the structure by the farmers is primarily due to its ability to impound soil, and to conserve surface runoff and nutrients upslope of the embankment. The deposition of sediment upslope of the embankment reduces the slope of the land and therefore contributes to the development of a bench terrace. The benching effect has some significant influence on nutrient, soil and moisture conservation which ultimately increases the crop yield potential of the land.

Conventional terrace designs have ignored farmers inclinations to maximize the productivity of all cultivable land whilst minimizing any wastage of land. The presence of an unproductive terrace channel area in this conventional terrace design has forced some small scale farmers to space terraces wide apart (against recommended terrace layout principles) to reduce the total number of these channel areas in their small holdings. The elimination of unproductive channels accompanied by stabilization of terrace embankments with fodder grasses would certainly sustain agricultural productivity of land. This would encourage the farmers to have the structures properly laid out as per design principles.

An attempt has been made to incorporate farmers inclinations into the new design of the fanya juu terrace whilst maintaining its effectiveness in soil erosion control. The modification of the conventional terrace design has focused on the elimination of an unproductive channel, reduced the depth of cut and increased the top width of the borrow area. The depth of cut has been restricted to the fertile top soil and provides for the utilization of the shallow borrow area for crop production immediately after the terrace is constructed. The new design also hastens the development of a bench terrace without any significant changes in soil fertility.

The applicability of fanya juu terraces to area specific conditions would depend on area specific factors like slope limits, aggregate stability, depth and nutrient status of soils, and rainfall intensity and duration, that significantly influence the design of these terraces. Soil moisture conservation is a major consideration and priority in the choice of fanya juu terraces in semi arid areas of Kenya.

With justifiable modifications to the conventional terrace design, to suit area specific environmental and socio economic farmer circumstances, the fanya juu terrace will continue to be the most popular and effective conservation structure on small scale farms in Kenya.

Conclusions.

The modified terrace design suggested integrates all design factors leaving room for area specific considerations. The design limits the soil borrow area to within the top soil. This ensures that the channel is cultivated and cropped immediately after the construction of the terrace.

The depth of storage of the embankment can be computed using available data on rainfall intensity, infiltration, ground slope and terrace spacing. Frequent maintenance of the embankment would help reduce the slope of the developing bench terrace.

Fanya juu terraces when well designed and constructed have proven to be the most effective erosion control structures on steep slopes. Since these terraces are constructed using hand labour only, the rate of development of bench terraces depends on rainfall erosivity, the slope of the land and the extent and frequency of cultivation.

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Trends in infiltration, runoff and soil loss of unstable crusting soils

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Abstract

Under the same hydraulic, hydrologic, topographic and soil surface conditions, different crusting soil types have the potential for exhibiting different infiltration, runoff and soil loss rates. Farmyard manure application is widely used in semi arid areas of Kenya (where crusting soils are dominant) to reduce crust formation, improve soil aggregation and permeability which would then facilitate better infiltration of rain water. However, this application could reduce the resistance of a soil to the erosive forces of rainfall and runoff and hence result in more soil loss. The hydrologic and physical behaviour patterns (infiltration, runoff, soil loss and soil crust strength) of four disturbed crusting soils (sandy clay loam plinthic luvisol, sandy loam chromic luvisol, sandy clay loam orthic luvisol and clay loam orthic luvisol) under two farmyard manure application rates (5 and 10 t ha^{-1}) were investigated under simulated rainfall conditions. The simulations were conducted over a period of 60 days and in three experimental phases of 20 days each.

The results obtained from this study showed that soil aggregation changed slightly with time and with manure application rates. The amount of surface runoff was significantly influenced by the day of simulation, soil type and soil surface conditions. There were significant increases in soil loss at P(0.05) with the addition of manure to the chromic and plinthic luvisols but not with the other two luvisols. Least soil losses were observed from the sandy clay loam orthic luvisol and the sandy loam chromic luvisol. Soil crust strength increased significantly when the crust moisture content was below 4%. The addition of 10 t/ha farmyard manure to the four soil types increased soil loss. This was attributed to improved soil aggregation and decreased soil bulk density (due to an increase in organic matter content). Generally, there was an increase in crust moisture content, improved soil aggregation and decreased crust strength with the increase in farmyard manure application.

Introduction

The dominant soils of ASAL (luvisols and acrisols) are characterized as having low organic matter, high salinity and/or alkalinity, an unstable structure, very strong surface sealing and crusting properties and high erodibility. ASAL soils range in their clay content from 10 - 20% (luvisols and acrisols) to 70% (Vertisols). The dominant clay minerals may be kaolinites or illites (luvisols and acrisols) and smectites (vertisols).

Surface sealing and crusting properties are enhanced by the high intensity, short duration rainfall prevalent in ASAL. This inherent soil property decreases infiltration rates of rainwater and consequently increases surface runoff. Very strong crusts (with high crust strength) are known to impede seedling emergence, rainwater infiltration and consequently lead to decreased crop yields. Increased and concentrated surface runoff along drainage ways and animal tracks is a major cause of soil degradation especially gully erosion in ASAL.

In Kaibon, West Pokot, it was observed that subsoil horizons of luvisols and acrisols which are the dominant soils, have dispersive properties and their exposure to concentrated runoff causes severe rill and gully erosion (Biamah, 1990). The management of these soils therefore requires minimum disturbance of subsoil horizons and improved rainwater penetration. Feasible interventions for minimizing surface runoff include maintaining ground cover (e.g cover cropping and mulching), modification of soil micro conditions (using minimum, conventional and conservation tillage) and increasing surface water storage through tillage (e.g tied ridges and micro catchments).

In order to design effective soil and moisture conservation systems for semi arid conditions, an essential prerequisite is the measurement of infiltration, soil loss and runoff from the dominant soils in the study area. Of significant importance is an understanding of inherent soil characteristics in relation to the effects of raindrop impact on crust formation and aggregate stability.

The objectives of this study were: to study the effects of farmyard manure application on infiltration, runoff and soil loss of disturbed luvisols under simulated rainfall; to monitor soil properties (moisture content, aggregation, organic matter content) and rainfall properties (rainfall intensity, amount and kinetic energy) influencing soil crusting and to determine the effects of changing crust strength (due to raindrop impact and different manure application rates) on infiltation, runoff and soil loss of the Kaibon luvisols.

Farmyard manure was expected to reduce the inherent surface sealing and crusting properties of luvisols and hence improve rainwater penetration into the soil and increase soil moisture storage.

Materials and methods

The four soil types (luvisols) used in this laboratory study were collected from A-horizons with depths of up to 15 cm. The soil types included a sandy clay loam plinthic luvisol, a sandy loam chromic luvisol, a sandy clay loam orthic luvisol(1) and a clayey loam orthic luvisol(2).

Table 1. below gives the percentage of soil separates. Chromic luvisol had 45 % fine and very fine sand, orthic luvisol (1) 36 %, orthic luvisol (2) 26 % and plinthic luvisol 35 %. Except for orthic luvisol (2), the other luvisols had a sand content of 59 % and over. The silt content was generally low while the clay content was higher than the silt content.

The major difference between the two orthic luvisols (1 and 2) used in this study was in the sand content. The sandy clay loam orthic luvisol (1) had a sand content of 67 % while the clay loam orthic luvisol (2) had a sand content of 34.5 % . The fine silt contents were 1.1 % and 10.1 % for the orthic luvisols(1) and (2) respectively. According to Hadas and Stibbe (1977), these properties are characteristic of soils that have crusting problems.

Prior to applying treatments, chromic luvisol had 1.1 % organic matter, orthic luvisol (1) 1.5 %, orthic luvisol (2) 5.6 % and plinthic luvisol 1.7 %.

Farmyard manure (mixture of cow dung and grass straws) was used as a soil amendment on the four soil types. A rainfall simulator described by Kamphorst (1987) was used in simulating the rainfall. A hand held cone penetrometer for top soil layers was used to monitor the penetration resistances of the soils.

Table 1.

Percentage distribution of soil separates of the four disturbed luvisols (Biamah and Chiti, 1992).

Particle size classification		Soil types (luvisols)			
		Chromic	Orthic(1)	Orthic(2)	Plinthic
Sand	Very	3.9	3.0	0.6	3.2
	Coarse	5.5	7.5	1.2	6.3
	Medium	22.1	21.6	7.1	15.8
	Fine	33.7	26.1	16.0	24.7
	Very Fine	11.0	9.5	9.6	9.9
Silt	Coarse	2.3	6.1	5.3	1.5
	Medium	1.8	2.1	11.7	4.1
	Fine	0.6	1.1	10.1	5.6
Clay		19.1	23.0	38.4	28.9
Textural class (USDA)		SL	SCL	CL	SCL

(SL = Sandy loam; SCL = Sandy clay loam; CL = Clay loam).

This experiment was based on a completely randomised design. Each block represented a particular soil type and consisted of nine trays which were made up of three treatments, each replicated three times. Two farmyard manure application rates of 5 t ha^{-1} and 10 t ha^{-1} and a control (no manure) were investigated. The effective total period of the experiment was 60 days divided into three experimental phases of 20 days each. Each phase involved rainfall simulation for four consecutive days, drying in the sun for five hours for four days and measuring penetration resistance and sampling for moisture content and organic matter content over the remaining sixteen days.

A day after loosening the topsoil surfaces and applying farmyard manure, rainfall simulation was initiated. Prior to simulation, the simulator was calibrated such that water discharge was 375 ml per minute. During simulations, sprinkling was conducted for 3 minutes giving a total of 1125 ml of discharged water. This is equivalent to 18 mm of rainfall at an intensity of 360 mm h^{-1} with a total kinetic energy of 637.2 Joules. During rainfall simulations, the sprinkling head was moved sideways in all horizontal directions to enable random distribution of drops over the soil surface.

The soil trays were on a slope of 5 % so the simulator frame had to be adjusted such that the top, where the sprinkler rests was horizontal. After the fourth day of simulation, the soil trays were taken out in the sun for five hours. This was repeated for the following three days after which the soil trays were kept in the laboratory where sampling for moisture content and organic matter content and measurement of penetration resistance were conducted. Runoff and soil loss were collected during each rainfall simulation. Soil aggregation was determined using the dry sieving method. Sampling for penetration resistance and moisture content were based on a grid system where the cells to be sampled were predetermined using random numbers. Three cells were selected per tray per each sampling day. Sampling was carried out a day after the fourth rainfall simulation and every fifth day thereafter up to the sixteenth day. Samples for organic matter and aggregate stability analyses were collected on the sixteenth day after the fourth simulation. On every seventeenth day after the fourth simulation, the soil surfaces were again broken up and simulations continued as before.

Two methods of data analysis namely analysis of variance (ANOVA) and regression analysis based on a 5 % level of significance were used. Through ANOVA, the main tests carried out covered the variations in the data for each tray, between trays and between the soil types (blocks). The variables analyzed included treatment, soil type, phase and simulation/sampling day effects.

Results and discussion

Soil properties

Soil aggregation

The dry sieving test showed that the chromic luvisol had 83% of aggregates that were less than 500 μm in size, the orthic luvisol (1) had 65%, the orthic luvisol (2) had 53% and the plinthic luvisol 68% of the aggregates. This was indicative of high friability of these soils when dry except for the orthic luvisol (2). The chromic luvisol had more aggregates that were less than 180 μm (35.5%). The orthic luvisol (1) had more aggregates in the 250 -500 μm and the < 180 μm size range while orthic luvisol (2) and plinthic luvisol had the largest percentages in the 250 - 500 μm range. Generally, orthic luvisol (2) had more of the larger aggregates than the other soil types. Chromic, plinthic and orthic (1) luvisols had increased percentages of aggregates less than 250 μm after 60 days for all treatments. There was a decrease in the percentage of aggregates between 250 μm and 2 mm and an increase in aggregates greater than 2 mm for 10 t ha^{-1} treatments for chromic luvisol and orthic luvisol (1). Plinthic luvisol had increased percentages of aggregates less than 250 μm in all the treatments. Orthic luvisol (2) had slight increases in aggregates that were less than 500 μm but significant changes were manifested in aggregate sizes that were greater than 1 mm. Soil aggregation remained stable only when the aggregates were less than 500 μm in size.

Generally, soil aggregation in most aggregate size ranges improved with the application of farmyard manure. Applying 10 t ha^{-1} manure increased aggregation in chromic luvisol and orthic luvisol (1). For the plinthic luvisol there was an increase in aggregates of sizes greater than 1 mm. The orthic luvisol (2), gained in aggregates of sizes less than 250 μm but lost in those sizes greater than 500 μm. An increase in the percentage of aggregates of very small sizes shows the ease with which soil crumbs were broken down.

Crust Organic Matter

Organic matter content in the soils increased when farmyard manure was added. After the first and second experimental phases, there were decreases in organic matter. The highest and lowest losses occurred where 10 t ha^{-1} manure was applied. Orthic luvisol (2) gave the highest losses of 1.2 % and 1.7 % during phases 1 and 2 respectively. The lowest losses were for orthic luvisol (1) after phase 1 and for chromic luvisol after phase 2. With the 5 t ha^{-1} manure application, orthic luvisol (1) had the highest increase of 0.46 % followed by plinthic luvisol with 0.35 %. At 10 t ha^{-1} farmyard manure application rate, orthic luvisol (2) had the highest increase (0.88 %) followed by orthic luvisol (1) with 0.74 %.

The addition of farmyard manure raised the organic matter content such that even after phase 2 of the experiment, trays with manure maintained a higher percentage of organic matter. All the soils and treatments showed a gradual decrease in organic matter content over time. The 5 t ha^{-1} treatments gave the highest decrease in organic matter except for plinthic luvisol where 10 t ha^{-1} gave the highest decrease. Lowest decreases were for 10 t ha^{-1} treatment in chromic luvisol and orthic luvisol (1) while for orthic luvisol (2) and plinthic luvisol, the controls had the lowest decreases. The decline in organic matter could be attributed to soil loss as wash load and also to decomposition.

Soil Surface Sealing and Crusting.

Surface sealing and subsequent crusting may have developed at a fast rate given that the soils, except orthic luvisol (2), had most of the initial crumbs of about 15 cm in diameter broken down during the first rainfall simulation. This observation agrees with data on aggregate stability in which aggregate stability was significant in the lower aggregate size of less than 500μm.

The breakdown of crumbs and aggregates provides the materials for both surface sealing and sediment yield. The sealing and compaction processes are therefore attained much faster if the rate of breakdown is high as was the case in this experiment.

Crusts of up to 2 cm thick were observed in all the soils. These crusts were characterized by a more compacted top layer. As the cone penetrometer was pushed into the soil, maximum resistance was attained from this top layer. The differences in penetration resistance were more distinct when moisture content in the crust fell below 4 %.

Infiltration.

All soil treatments showed infiltration trends that decayed with time. The highest total infiltrated water was recorded on the first day while the lowest was on the fourth day of simulation. There were significant soil type effects during phases 2 and 3. Orthic luvisol (1) had the highest total infiltration throughout the experiment (see Figure 1). During phases 2 and 3, this soil type generated no runoff on the first day of simulation giving the highest infiltration value of 18 mm. The plinthic luvisol had the lowest infiltration throughout the simulation.

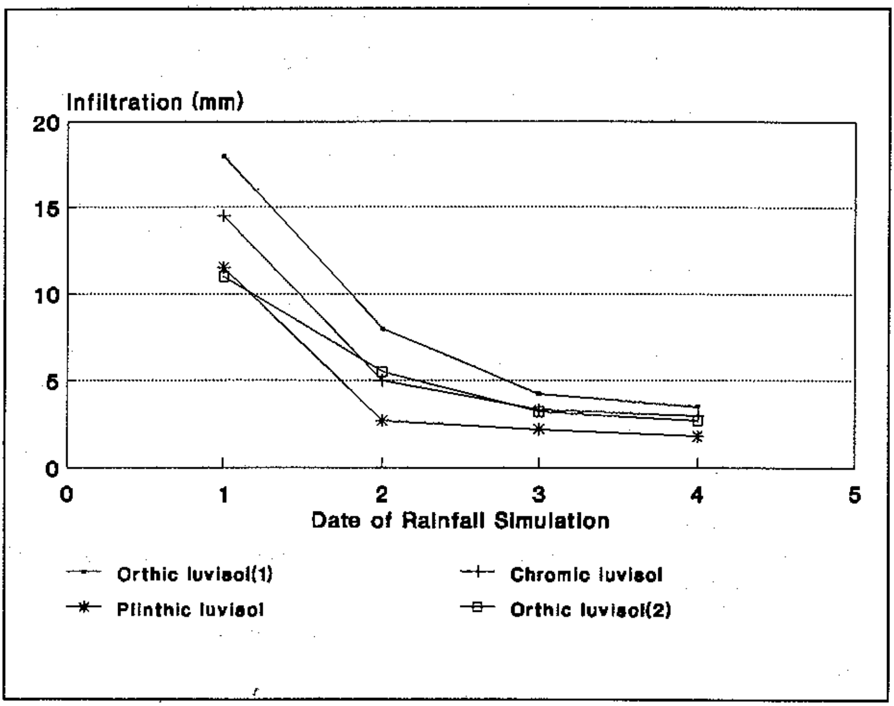


Fig. 1. Mean infiltration capacities for each soil type during rainfall simulations (Biamah and Chiti, 1992).

Rainfall characteristics directly contributed to the pattern of infiltration curves by quickly reducing the infiltration capacity to below the rainfall rate. This was particularly so because the rainfall rate of 360 mm h^{-1} that was applied could have been greater than the saturated conductivities of the soils. The large size of raindrops easily disintegrated the aggregates and formed small craters. These caused surface sealing and puddling and consequently reduced infiltration. By the fourth day of simulation, the soil type effects were weakened by the effect of rainfall hence the reduced soil type effects on infiltration on this day.

Antecedent soil moisture also influenced infiltration. Table 2 shows that day 1 of phase 1 had less infiltrated water (8.3 to 10.9 mm) than on the same day during phases 2 and 3 which had between 10.1 and 18 mm. Similarly, all the simulation days in phase 1 had lower values than phases 2 and 3 while subsequent simulation days after day 1 also had lower values. Infiltration capacities on the second and fourth day of simulation were reduced to about 50 and 25 % respectively (see Table 2).

Table 2.

Ranges of cumulative infiltration for all the soil types during the simulation (Biamah and Chiti, 1992).

Simulation day	Cumulative infiltration (mm)		
	Phase 1	Phase 2	Phase 3
1	8.2 - 10.9	10.1 - 18.0	11.8 - 18.0
2	2.1 - 5.3	3.6 - 9.9	4.0 - 9.8
3	1.7 - 3.5	1.8 - 5.1	1.9 - 5.7
4	1.5 - 3.6	1.6 - 4.1	1.7 - 3.5

Time to Runoff.

The ranges in time to runoff for all soils and phases are given in Table 3. The longest time to runoff during phase 1 was 93 secs. on day 1 while on the same simulation day, phases 2 and 3 did not generate runoff.

Phases 2 and 3 gave the longest time to runoff (>180 secs) on day 1. This was because the soils were not pre-wetted prior to rainfall simulation as was the case in phase 1. As simulation progressed, the time dropped to between 10 and 28 secs. These results are expected due to the influence of antecedent soil moisture and initial soil surface conditions (Falayi and Lal, 1979).

Table 3.

Ranges in time to runoff in seconds for all soil types (Biamah and Chiti, 1992).

Simulation day	Phase 1	Phase 2	Phase 3
1	52 - 93	59 - >180	103 - >180
2	13 - 29	13 - 55	25 - 57
3	11 - 29	11 - 27	15 - 34
4	12 - 20	10 - 28	15 - 27

All soils did not show any significant differences in time to runoff between the same treatments and phases. However the treatment effects on the same day of rainfall simulation were significant at P(0.05) on day 4 for chromic luvisol, and on day 1 for orthic luvisol (1) during phase 1. The 5 t/ha treatment in chromic luvisol took longer to generate runoff than other treatments on day 1. For the orthic luvisol (1), 10 t/ha treatment took longer to runoff on day 1. The control in chromic luvisol took significantly longer (22.7 secs) than both 5 and 10 t ha^{-1} treatments with 17.7 and 17.3 secs respectively. Similarly, 10 t ha^{-1} treatment in orthic luvisol (1) took longer than 5 t ha^{-1} and the control with 67.7 secs, 59.3 secs and 55.3 secs respectively. The control in chromic luvisol took longer to generate runoff probably due to lower organic matter content since incorporating farmyard manure into the soil increased organic matter content for the 5 and 10 t ha^{-1} treatments.

There was a general trend of decreasing time to runoff between treatments and soil types in each of the phases during the simulations. After the second day of simulation, all soils yielded similar times to runoff regardless of the treatment. This was so because surface sealing and crusting occured in all soil types.

Surface Runoff.

The highest and lowest maximum amounts of runoff recorded for individual rain storms were 16.4 mm (91%) and 14.4 mm (80%) respectively on the fourth day of rainfall simulation. The lowest and highest minimum runoff values were 0 and 9.7 mm (54%) on the first day. There was a steady increase in runoff from day 1 upto day 3 when runoff started to stabilize. Stabilization started when runoff reached about 70% to 80% of the total rainfall (see Figure 2). The highest mean percentage runoff recorded was 82 % for a chromic luvisol while the lowest was 50 % for an orthic luvisol (1). In most cases, the day of simulation significantly influenced the amount of surface runoff. These effects could be attributed to changes in antecedent soil moisture and soil surface conditions. The lowest percentage runoff was observed on the first day of each phase. This trend was more pronounced and distinct in phases 2 and 3 than in phase 1. The largest amounts of surface runoff were observed on days 3 and 4 of all phases.

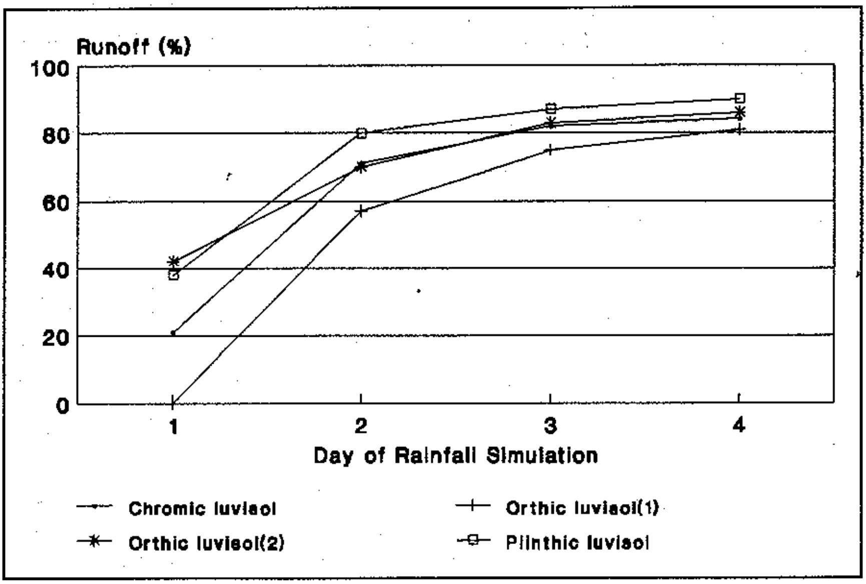


Fig. 2. Typical surface runoff patterns for all the soil types during the simulation experiment (Biamah and Chiti, 1992).

Statistically, no significant differences were observed between treatments and phases. Farmyard manure application therefore, did not have any effect on surface runoff. This could have been due to the high intensity of the rainfall (360 mm h^{-1}) and the large size of the raindrops (5.9 mm in diameter). More runoff was expected from the controls than the 5 and 10 t ha^{-1} treatments since the latter two had farmyard manure which improved aggregation. However, rainfall characteristics and the inherent properties of the soils necessitated easy aggregate breakdown for all treatments. Consequently, there were no great differences in the resulting runoff for all the treatments.

There were more distinct soil type effects on runoff in phase 2 and 3 than in phase 1. These effects also influenced the amount of runoff on each simulation day.

Generally, there were significant increases in amounts of runoff from the first to the fourth day of simulation. During the fourth day of rainfall simulation, all the soils had about the same amounts of runoff. On this day, runoff responded more to soil surface conditions than to soil properties.

Table 4.

Coefficients of variation in surface runoff for each treatment in each experimental phase (Biamah and Chiti, 1992).

Luvisol type	Treatment	Phase 1		Phase 2		Phase 3	
		a	b	a	b	a	b
Chromic	Control	-	8.1	43.3	10.7	41.5	11.0
	5 t/ha	-	8.9	41.2	9.1	44.5	11.7
	10 t/ha	-	4.4	41.1	9.6	43.2	8.8
Orthic (1)	Control	-	7.4	65.0	21.4	66.7	25.0
	5 t/ha	-	8.7	63.8	18.3	64.8	20.9
	10 t/ha	-	11.3	66.9	25.4	63.1	16.3
Orthic (2)	Control	28.6	10.8	27.6	10.7	34.9	14.1
	5 t/ha	22.5	5.4	21.1	9.7	31.6	11.9
	10 t/ha	37.4	9.5	23.6	9.8	32.6	10.7
Plinthic	Control	25.3	7.6	31.4	10.4	40.4	7.6
	5 t/ha	23.3	5.2	26.7	7.8	41.0	6.7
	10 t/ha	21.9	6.8	30.5	7.0	41.3	7.1

(a = day 1 included. b = day 1 excluded)

Coefficients of variation for surface runoff were low. They ranged from 4.4 to 25% (day 1 excluded) and from 21 to 67% when day 1 of each phase was included (see Table 4). The coefficients showed high variations on the first day of simulation due to antecedent soil moisture, soil surface conditions and the development of a surface seal and crust.

Regression analysis showed that kinetic energy and time to runoff significantly influenced runoff. Kinetic energy accounted for over 72% of the variation in runoff for all soils while organic matter did for less than 0.5%. Time to runoff accounted for over 90% of the variation in runoff.

Soil loss.

The results obtained from this simulation study showed phase variations in soil loss. In phase 1, the treatments were pre-wetted and all soil types exhibited high infitration rates due to the cloddy soil surface conditions that enhanced infiltrability. During this phase, soil loss decreased with time (see Figure 3) due to the increase in soil surface sealing by the beating action of raindrops. In phases 2 and 3 (see Figures 4 and 5), the soil loss increased from day 1 upto a maximum on day 2. The increase in soil loss from day 1 to 2 was attributed to the low initial soil moisture and the slow integration and detachment of soil particles. After day 2 soil loss gradually decreased due to the increase in surface sealing induced by the slaking caused by the high rainfall intensity during rainfall simulation.

The highest total sediment yield was obtained from the plinthic luvisol during phase 2 (85.7 g). The lowest sediment yield for the same soil was 34 g during phase 1. Orthic luvisol (2) ranked second with 72 g in phase 2 but it had a minimum value of 28 g during phase 1. Orthic luvisol (1) was the third having 49.7 g in phase 1. Chromic luvisol had the lowest maximum sediment yield of 43 g in phase 1. The lowest minimum sediment yield of 9 g was obtained from orthic luvisol (1) during phase 3.

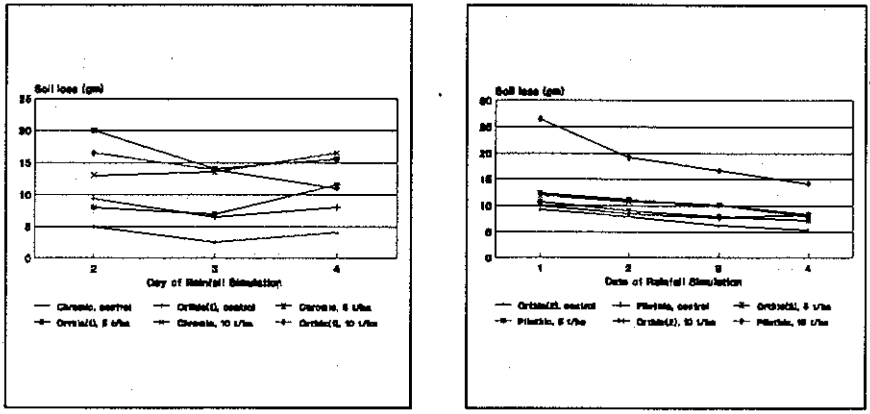


Fig.3. Soil loss for Chromic, Orthic(1), Orthic(2) and Plinthic luvisols during phase 1 (Biamah and Chiti, 1992).

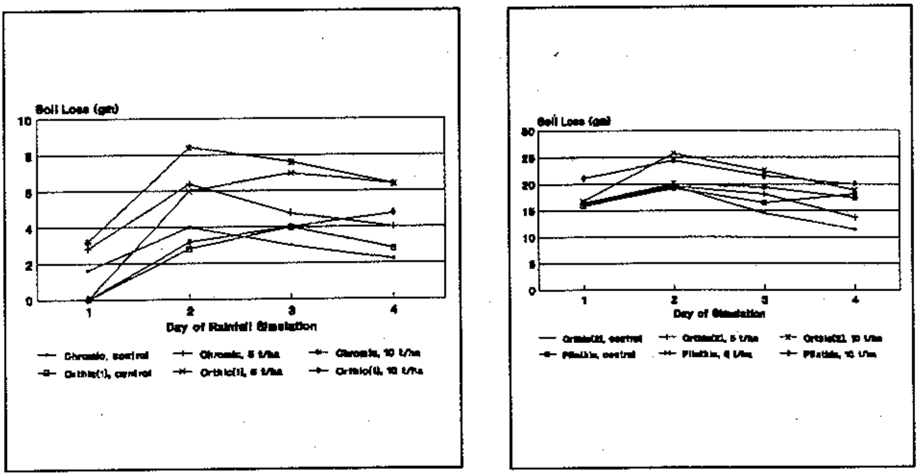


Fig. 4. Soil loss for Chromic, Orthic(1), Orthic(2) and Plinthic luvisols during phase 2 (Biamah and Chiti, 1992).

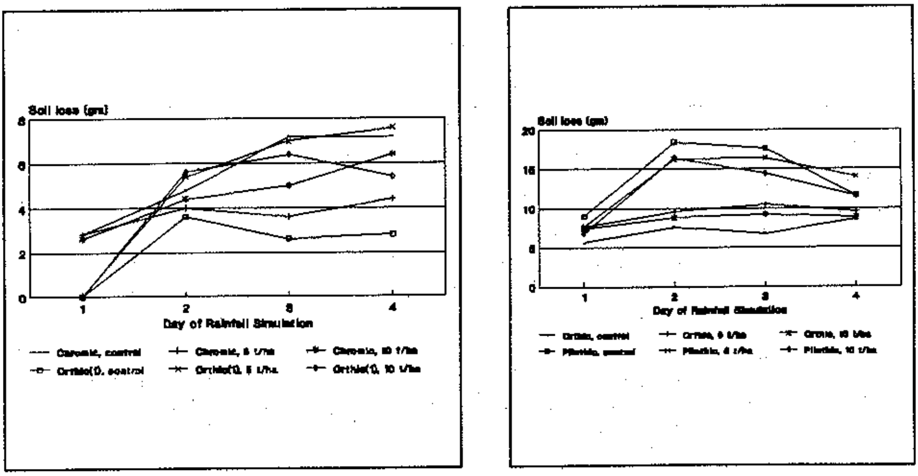


Fig. 5. Soil loss for Chromic, and Orthic(1), Orthic(2) and Plinthic luvisols during phase 3 (Biamah and Chiti, 1992).

Table 5

Coefficients of variation in soil loss for each treatment in each experimental phase (Biamah and Chiti, 1992).

Luvisol type	Treatment	Phase 1		Phase 2		Phase 3	
		a	b	a	b	a	b
Chromic	Control	-	30.7	41.6	33.5	38.3	24.2
	5 t/ha	-	33.4	51.3	46.1	21.1	19.5
	10 t/ha	-	31.9	59.8	52.6	37.6	25.5
Orthic (1)	Control	-	33.5	90.7	59.7	80.9	47.3
	5 t/ha	-	43.7	105.7	76.3	89.9	58.6
	10 t/ha	-	21.7	80.4	46.7	71.0	33.0
Orthic (2)	Control	227.7	21.6	38.0	28.3	22.9	20.0
	5 t/ha	24.1	22.7	31.1	30.8	46.0	43.3
	10 t/ha	47.4	42.6	27.0	27.3	17.6	14.3
Plinthic	Control	30.6	33.6	33.7	32.7	33.4	26.2
	5 t/ha	47.5	51.2	53.7	53.8	57.4	49.3
	10 t/ha	5.0	67.9	37.4	27.4	46.2	39.4

(a = day 1 included. b = day 1 excluded)

Table 5 shows that for chromic luvisol, coefficients of variation went over 50 % in certain instances. Orthic luvisol (1) reached about 100 % while for orthic luvisol (2) and plinthic luvisol, the coefficients reached 47 and 75 % respectively. This high variation accounted for the significant differences between some replicates.

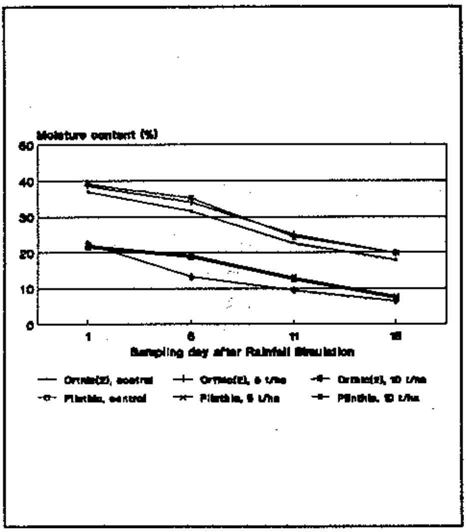
Treatment effects in each phase were significant in phases 1 and 2 for chromic luvisol. The 10 t ha^{-1} treatments gave higher soil loss (43 g in phase 1 and 41 g in phase 2) than the 5 t ha^{-1} and the control. In phase 1, 5 t ha^{-1} treatments were still higher than the control while in phase 2 the two were similar. Orthic luvisol (1) showed that 5 and 10 t ha^{-1} treatments had statistically higher soil loss (50 and 41 g respectively) than the control which had 23 g. 5 and 10 t ha^{-1} treatments were however not significantly different. Plinthic luvisol had the 10 t ha^{-1} treatment yielding higher sediment (79 g) than both 5 t ha^{-1} and the control (42 and 34 g respectively). These results are depicted in Fig. 15 where the graphs for 10 t ha^{-1} treatment lie well above those of 5 t ha^{-1} and the control. The controls ranked lowest with 2.4 g of soil on day 3 and 3.7 g on day 4. Orthic luvisol (2) had 5 and 10 t ha^{-1} treatments yielding higher soil loss than the control on day 4. During phase 3, the control had significantly higher soil loss (7.2 g) than the 5 and 10 t ha^{-1} treatments on day 3 for chromic luvisol.

Crust Moisture.

The crust moisture content for all soil types decayed with time. The moisture content for chromic luvisol and orthic luvisol (1) decreased sharply five days after rainfall simulation. For orthic luvisol (2) and plinthic luvisol the decrease was gradual. This gradual decrease was attributed to the weather rather than to soil properties. These trends were expected since the longer the soil stays without moisture replenishment, the drier it becomes. No phase effects were observed. Day effects were very highly significant on the 6th day after rainfall simulation.

Soil types had some differences which were masked by weather influences. All the same, orthic luvisol (2) had more moisture in the crusts for all treatments. This was followed by plinthic luvisol and lastly by chromic luvisol and orthic Luvisol (1) (see Figures 6 to 8). The orthic luvisol (2) had more clay and silt than the other soils. Clay retains more moisture than sand and hence the significant differences in moisture content were therefore attributed to fine particle distributions of the different soil types.

Significant treatment effects were observed on days 1 and 6 during phase 1 for orthic luvisol (2). On these days, 5 and 10 t ha^{-1} treatments had more moisture content in the crusts than the control.



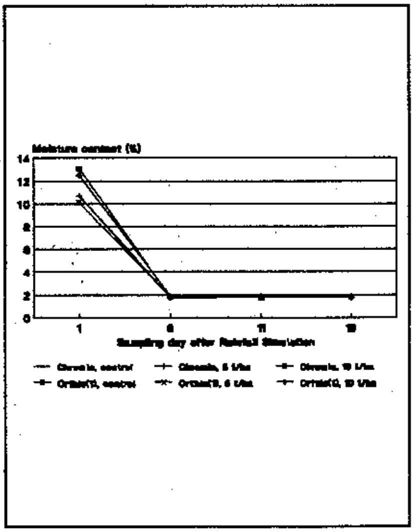


Fig. 6. Crust moisture content for Plinthic, Orthic (1), Plinthic and Orthic (2) luvisols during experimental phase 1 (Biamah and Chiti, 1992).

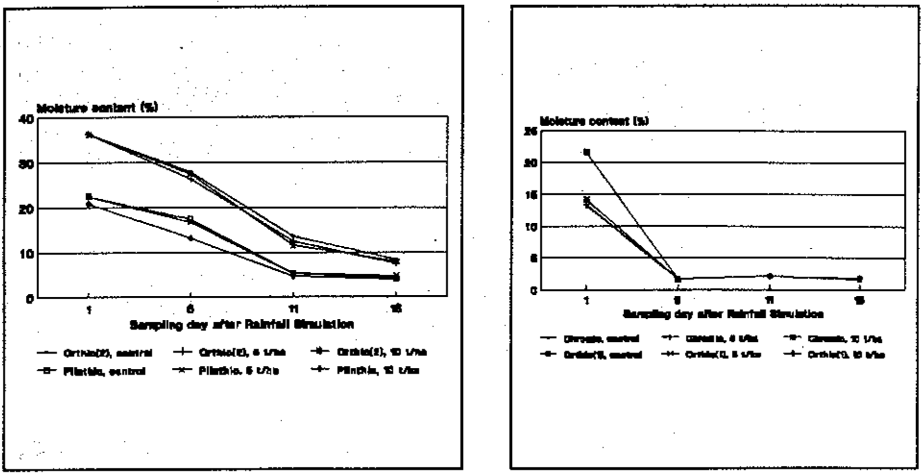


Fig. 7. Crust moisture content for Plinthic, Orthic (1), Chromic and Orthic (2) luvisols during experimental phase 2 (Biamah and Chiti, 1992).

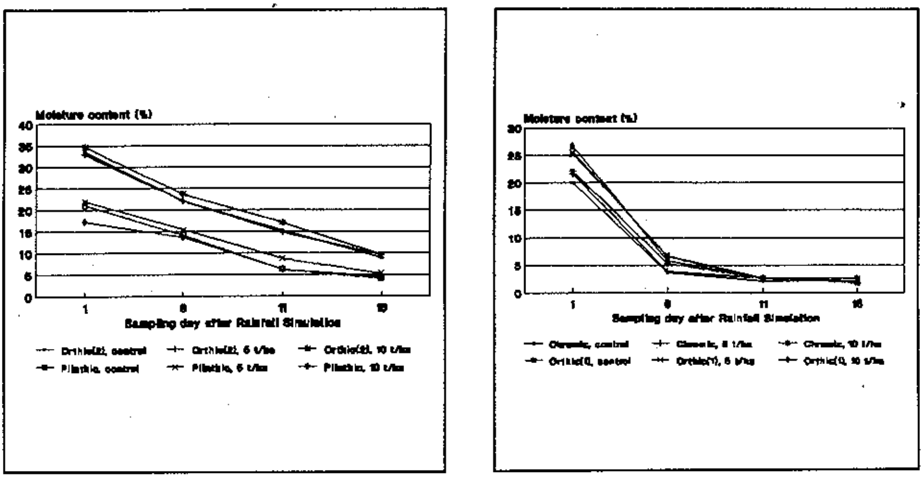


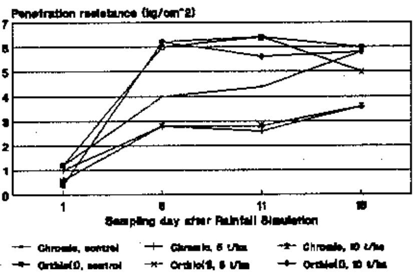
Fig.8. Crust moisture content for Chromic, Orthic (1), Plinthic and Orthic (2) luvisols during experimental phase 3 (Biamah and Chiti, 1992).

Penetration Resistance.

Cone penetration resistance was used to determine the strength of soil surface crusts. Orthic luvisol (1) had asymptotic curves during all the phases while chromic luvisol reached a maximum value during phases 2 and 3 but not during phase 1. Plinthic and orthic(2) luvisols did not reach their maxima even on the 16th day after simulation. This was due to the high relative humidity during the experiment. The penetration resistances in the chromic, orthic (1) and orthic (2) luvisols (range of 3.5 to 6.0 kg cm^{-2}) were lower than in the plinthic luvisol (range of 15 to 25 kg cm^{-2}) after day 11 during phases 1 and 3. During phase 2, the differences became greater after day 6 (see Figures 9 to 11).

By day 6, chromic and orthic (1) had attained penetration resistance values of over 3 kg cm^{-2} unlike plinthic and orthic (2) luvisols which had less than 3 kg cm^{-2}. This was because of the high relative humidity during the experiment in the latter soil types. Soil type effects on each sampling day gave significant differences during all the phases except on day 1 of phase 3.

Maximum penetration resistance for all the four soil types was attained during phase 3. The highest maximum value was for the plinthic luvisol which had attained 31 kg cm^{-2} on day 16. This was followed by the chromic luvisol (14 kg cm^{-2}) on day 11, then the orthic luvisol (2) with 11 kg cm^{-2} on day 11 and lastly the orthic luvisol (1) with 8 kg cm^{-2} on day 16.



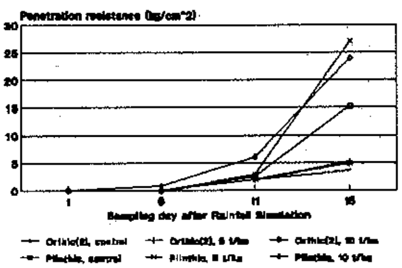


Fig. 9. Penetration resistance for Chromic and Orthic (1), Plinthic and Orthic (2) luvisols during phase 1 (Biamah and Chiti, 1992).

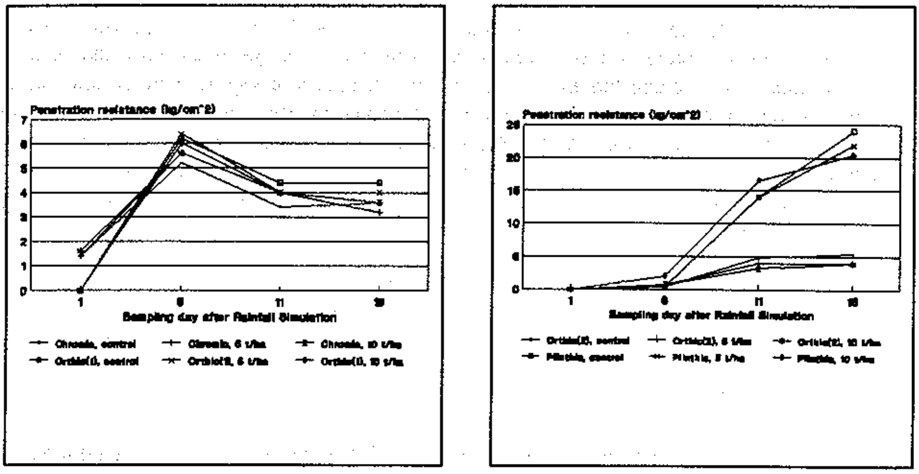


Fig. 10. Penetration resistance for Chromic and Orthic (1), Plinthic and Orthic (2) luvisols during phase 2 (Biamah and Chiti, 1992).

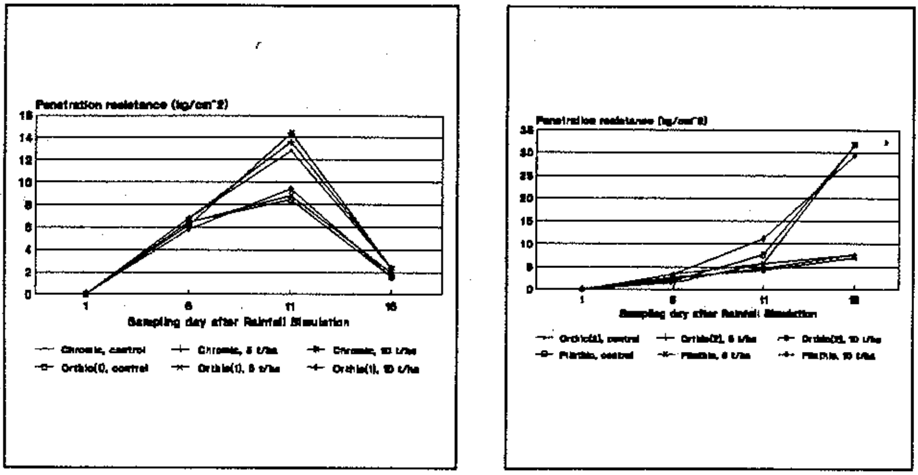


Fig. 11. Penetration resistance for Chromic and Orthic (1), Plinthic and Orthic (2) luvisols during phase 3 (Biamah and Chiti, 1992).

Chromic and orthic (2) luvisols reached maximum values at the time when moisture content was not at the lowest unlike plinthic and orthic (2) luvisols that had a gradual increase in penetration resistance with moisture depletion. Similar trends were shown during phases 1 and 2 of the experiment and suggest that cohesion of aggregates and soil particles were attained at different moisture contents depending on the soil type. Differences in organic matter and particle size were also closely associated with the differences in penetration resistance.

Conclusions.

Soil Aggregation.

With time, there was an increase in the percentage of aggregates less than 250 μm and a decrease in those aggregates greater than 250 μm. The addition of farmyard manure especially the 10 t ha^{-1} treatments lowered the increase in the percentage of aggregates less than 250 μm. The 10 t ha^{-1} treatments also increased aggregation of soil aggregates greater than 2 mm in size.

Farmyard manure slightly improved soil aggregation but this was not sufficient to enable the soils to withstand the destructive force of raindrops. For the period of study, aggregation in the different soil types did not result in reduced soil loss, runoff and soil surface crusting. There was some reduction in penetration resistance (crust strength).

Increases in organic matter content were recorded for plinthic, orthic (1) and orthic (2) luvisols. These three soil types had higher initial organic matter content than the chromic luvisol. At the end of 60 days, all soils recorded decreased organic matter content. Orthic luvisol (2) and plinthic luvisol had higher losses with manure treatments than with the controls. Chromic luvisol and orthic luvisol (1) lost more organic matter from 5 t ha^{-1} than 10 t ha^{-1} treatments. In spite of the losses in organic matter, soil aggregation improved slightly. Losses in organic matter to levels that did not surpass the initial organic matter content did not adversely affect soil aggregation.

Time to Runoff.

Farmyard manure treatments for chromic luvisol and orthic luvisol (1) showed some significant decrease in the time to runoff. Manure application in luvisols can therefore either increase or decrease the time to runoff depending on the properties of that luvisol.

During the first days of the simulation, there were longer times to runoff mainly due to cloddy soil surface conditions, higher porosity and the lower antecedent soil moisture.

Surface Runoff

Application of manure did not significantly influence the amount of runoff. Regression analyses indicate that cumulative kinetic energy explained more for the variation in runoff (over 70 %) than organic matter (less than 5 %) while the time to runoff accounted for over 90 % at P(0.05). Initially, cloddy surfaces due to soil preparations enhanced surface depressional storage while smooth and sealed surfaces led to more runoff.

Soil surface sealing and crusting led to increased surface runoff. All the soils reached runoff rates of over 60 % on the last day of simulation. On bare and exposed surfaces of the luvisols, runoff reached high rates over a short time regardless of the treatments. Rainfall characteristics could have played a significant role in the process of runoff generation considering that the disintegration of soil clods occurred easily under the high rainfall intensity. This could have led to compaction, low porosity and quick topsoil layer saturation.

Soil loss.

A number of factors including particle size distribution and degree of soil aggregation, could have influenced the soil losses of the luvisols and hence helped explain why there were high variabilities among the soil types. Time to runoff, surface runoff, organic matter and kinetic energy of the rainfall did not adequately explain the variation in soil loss. High rainfall intensity and drop size were instrumental in aggregate breakdown, quick soil saturation and increased runoff.

Farmyard manure application increased soil loss in chromic luvisol, orthic luvisol (1) and plinthic luvisol particularly during the first phase. This suggests that more soil is bound to be lost during the first rainfall events if farmyard manure has been applied. Given the short decomposition period of manure, the physical and chemical reactions might not have had maximum effects. Where soil aggregation had improved, soil loss might have been more in the form of whole aggregates than discrete soil particles.

Crust Moisture.

The results obtained showed that soil properties were influential in determining the amount of moisture that was retained in the soil. Orthic luvisol (2) which had the highest clay content responded positively to treatments. Addition of farmyard manure to orthic luvisol (2) helped to increase moisture content unlike the other soil types which did not show significant differences in moisture content with manure application.

The increase in moisture content of the crust in orthic luvisol (2) was a result of the interaction of organic matter with other soil properties such as clay content, silt content and pore space.

Penetration Resistance.

Penetration resistance depended on the soil moisture content as was expected but each soil type had its own moisture content level at which maximum penetration resistance was reached. Chromic and orthic (1) luvisols for instance, attained maximum penetration resistance before the minimum moisture contents were reached and thus depicting asymptotic trends. The plinthic and orthic (2) luvisols had increasing penetration resistance with decreasing moisture content.

The highest penetration resistance was recorded from the controls during phase 3. This links with organic matter content and shows that organic matter content was important in reducing penetration resistance. Less organic matter content led to higher penetration resistance just as the controls had the lowest organic matter content and hence the highest penetration resistance. Generally, both soil moisture and organic matter content influenced the penetration resistance in all the four soil types. All the four soil types investigated developed structural crusts whose thickness ranged between 0.5 to 2 cm. The highest penetration resistance did not exceed 32 kg cm^{-2}.

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EROSION LOSSES OF HUMUS AND BIOGENEOUS ELEMENTS IN SERBIA

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ABSTRACT

Erosion processes cause different negative effects to soil properties, among which the losses of humus and nutrients are of significance, as soil fertility is substantially reduced. The eroded mineral soil retains a certain proportion of the less-soluble phosphorus and potassium, which are retained or fixed in an unavailable form, by the soil clay minerals. The losses from arable land then contribute to the nutrient enrichment or eutrophication of the waters into which they drain.

The paper deals with the aspect of the losses of humus, total nitrogen and readily available phosphorus and potassium, caused by water and wind erosion in Serbia. The investigation was carried out in small and medium experimental watersheds in the regions of Serbia, as well as in wind gauging stations in Vojvodina (North Serbia). The paper presents the results of long-term investigations.

INTRODUCTION

More than 86 % of total area of Serbia (88,361 km^2) is attacked by erosion (76,354.43 km^2). In upland region of Serbia (more than 70 % of total area) the dominant form of erosion is water erosion, whereas in Vojvodina (lowland in the North), wind erosion is dominant. The data on sediment yield and transport have been obtained from the map of erosion of Serbia, made according to the method by Gavrilović (1972). Total average annual sediment yield in Serbia amounts to 37,249,975 m^3yr^{-1} (421.57 $m^3yr^{-1}km^{-2}$), while annual total sediment transport is 9,350,765 m^3yr^{-1}, and specific annual sediment transport is 105.80 $m^3yr^{-1}km^{-2}$.

Deflation process in the zone of steppe - savanna climate in Europe occurs in the large plain of Vojvodina, which is a corn-field and a region of particular importance to Serbia and Yogoslavia. According to the results of the research, average annual transport of wind deposit amount to 2 t ha^{-1}.

Together with sediment, manures and fertilizers, as well as the pesticides used in agricultural production, are transported to the streams and air. In this way, in addition to soil loss from the sloped land and wind-attacked land, water and wind erosion processes cause various negative effects to soil properties and soil fertility, usually manifested by humus and biogeneous element (nutrient) losses.

The losses of biogeneous elements from the soil (caused by water and wind erosion) reflect themselves in poorer plant production, whereas their deposition in water storages accelerates the process of eutrophication.

The paper deals with the aspect of the losses of humus, total nitrogen and readily available phosphorus and potassium caused by water and wind erosion of soil in Serbia.

OBJECTS OF RESEARCH

The research was carried out in four regions in Serbia:

1. South-East Serbia - the watersheds of the rivers Kalimanska Reka and Repinska Reka, left tributaries of the Juž Morava, near the town Vladičin Han.
2. Cenral Serbia - the watershed of the river Jasenica, left tributary of the Velika Morava.
3. West Serbia - the watershed of the streams Dubosnički Potok, Lonjinski Potok, and Djurinovac Potok, left tributaries of the river Drina, near the town Ljubovija.
4. Region of Subotica-Horgos Sands, North of Vojvodina, where the research dealt with the losses caused by wind erosion.

All of the experimental watersheds are in a hilly-mountainous region, which is illustrated by their topographic characteristics presented in Table 1. The watersheds are in the region of temperate - contiental climate.

Soil types and land use in the watersheds have been presented in Table 1.

Table 1. Main parameters of the researched watersheds.

Parameters Watersheds	F km^2	G km^{-2}	N	I %	Dominant soil type	
Kalimanska R.	16.0	2.10	810.0	40.86	distric cambisol	
Repinska R.	7.82	2.15	641.0	30.60	distroc cambisol	
Jasenica	83.76	1.63	507.8	22.40	distroc cambisol	
Dubosnički P.	1.25	3.26	487.9	47.24	brown acid soil	
Lonjinski P.	0.77	2.38	363.9	38.87	brown acid soil	
Djurinovac P.	0.54	4.04	299.7	43.59	brown acid soil	
Watershed	Vegetative cover %					Coeff. of erosion Z
	forest	grassland	orchard	arable	bare land	
Kalimanska R.	50.50	19.48	6.44	22.92	0.30	0.36
Repinska R.	55.03	5.28	0.29	39.30	1.10	0.37
Jasenica	44.45	29.98	0.20	33.00	0.03	0.38
Dubosnički P.	71.38	15.98	6.29	4.49	1.86	0.56
Lonjinski P.	80.54	10.97	3.00	5.49	-	0.34
Djurinovac P.	66.26	14.04	3.10	12.98	3.62	0.49

Water erosion of various intensity is represented by the value of the coefficient of erosion - Z, according to S. Gavrilović (Gavrilović, S., 1972), in Table 1. The weakest process of erosion occurs in the Lonjinski Potok, and the most servere in the Dubosnički Potok.

The Subotica - Horgos Sands are situated between the Danube and Tisza Rivers, average length 48 km and diameter 5-11 km, area cca 24,000 ha. It is a country of orchards, grape and vine, with more than 33 % land under vineyards and orchards, cca 20 % forests and woodlands, and more than 34 % under grassland. On the sand, as the parent substrate, several types of soil have been formed: initial soil on sand, brown steppe soil on sand, and sandy cheronozem, etc.

The climate of the area is conditioned by the position of the Pannonian Plain and can be defined as a steppe - Pannonian mondifications of the continental climate, with warm summers, cold winters and strong winds. As for their intensity and frequency, North-West and North winds are the dominant winds. Alle the above characteristics contribute to the intense wind erosion with all its consequences.

METHOD

Direct measurements and monitoring of hydrologic and microclimate parameters were undertaken in all the experimental watersheds. Within the hydrologic research, a cross section was used to monitor runoff, measured by limnigraph. Suspended sediment transport was measured by taking water samles and by determining the concentration of solids.

In the research of wind erosion, the comparative method of stationary observation by wind-gauge stations was applied at especially selected erosion plots, of which one, used for agricultural production, was not protected, while the other was protected with forest plantings. Experimental stations recorded: quantity of aeolian deposition, wind frequency and velocity, air and soil temperature, air humidity and soil moisture, etc.

The samles of sediment were analysed for humus content (Tjurin's method), total nitrogen (Kjeldahl' method), and readily available phosphorus and potassium contents by Al-method (Enger-Riehm).

RESULTS OF RESEARCH

Humus, as an important factor of the adsorptive capacity of the soil, determines the biodynamics of the soil formation processes and the conditions of the mineral nutrition of plants. Humus contains averagely up to 99 % reserves of soil nitrogen, about 90 % sulphur, a considerable part of phosphorus and other nutrients. Erosive activity of water, first of all, results in the loss of the above elements from the soil.

The results of the research have been presented in Table 2 and 3. For the different periods of research, in some experimental watersheds and wind-gauge station at D.Tavankut (Subotica-Horgos Sands), the average annual losses of humus and biogeneous elements have been given in kg ha^{-1}.

Table 2. Mean annual losses of humus and biogeneous elements from experimental watersheds.

Watershed	Period	Mean annual losses in kg ha^{-1}			
		Humus	total N	P_2O_5	K_2
Kalimanska R.	1978-1985	33.30	1.37	0.051	0.045
Repinska R.	1978-1985	70.80	2.22	0.088	0.099
Jasenica	1980-1988	27.33	1.44	0.080	0.086
Dubosnički P.	1986-1988	84.98	6.12	1.143	3.520
Lonjinski P.	1986-1988	44.40	2.49	0.440	2.710
Djurinovac P.	1986-1988	55.81	2.54	0.635	5.275
AVERAGE		52.77	2.70	0.406	1.956

As it can be seen from Table 2, the lowest loss of humus was observed in the river Jasenica watershed (27.33 kg ha^{-1}), and the highest in the Dubosnički Potok (84.98 kg ba^{-1}). The lowest loss of total nitrogen was recorded in the Kalimanska Reka watershed (1.37 kg ha^{-1}) and the higbest in the Dubosnički Potok watershed (6.12 kg ha^{-1}). The lowest losses of P_2O_5 (0.051 kg ba^{-1}) and K_2O (0.045 kg ba^{-1}) were recorded in the Kalimanska Reka watershed, and the highest losses were recorded in the watershed Dubosnički Potek (P_2O_5 - 1.143 kg ha^{-1}) and Djurinovac Potok (K_2O - 5.275 kg ha^{-1}). The lowest losses were observed in the wateshеds with less intensive water erosion (Kalimansk Reka), whereas th highest losses were recorded in the Dubosnički Potok and Djurinovac Potok watersbeds (K_2O), with the most intensive erosion processes.

Average annual losses of humus and biogeneous elements resulting from wind erosion, based on the measurements of wind-gauge station at D. Tavankut, have been presented in Table 3.

Table 3. Mean values of humus and biogeneous elements in the aeolian deposition in %.

Period	aeolian dep kg m^{-1}	humus %	total N %	P_2O_5 %	K_2O %
1980-1989	5.48	5.29	0.514	0.026	0.030

Average annual losses of humus and biogeneous elements were: average annual quantity of aeolian deposition - 5.480 kg km; annual loss of bumus - 290 kg km; total nitrogen - 28.0 kg km^{-1}; P_2O_5 - 1.5 kg km and K_2O - 1.6 kg km^{-1}.

Based on the above research, annual erosion losses of humus and biogeneous elements in Serbia were evaluated. In the calculation, it was considered that water erosion is dominant in upland regions in Serbia, and in Vojvodina wind erosion is dominant and water erosion i very weak. The results have been presented in Table 4. Tbe results show that the loss is great. It should be emphasized that the losses of the above elements resulting from wind erosion, are about 50 % of the total losses, although the area where wind erosion is dominant is less than one third of the area with water erosion.

Table 4. Annual losses of humus and biogeneous elements in Serbia.

Region Erosion type	Area km^2	Losses of humus and biogeneous elements $t\ year^{-1}$			
		Humus	Total N	P_2O_5	K_2O
Serbia (without Vojvodina watererosion	66,855	352,793.84	18,050.85	2,714.31	13,076.84
Vojvodina wind erosion	21,205	227,533.48	22,108.17	1,118.31	1,290.36
TOTAL	88,361	580,327.32	40,159.02	3,832.62	14,367.20

CONCLUSION

Water erosion is the dominant process of erosion in hilly-mountainous regions in Serbia and wind erosion is the dominant process of erosion in Vojvodina.

The results of the research show that the losses of humus, total nitrogen, readily available phosphorus and potassium are, first of all, determined by the intensity of erosion and the quantity of sediment yield in the given conditions. The loss was also affected by the level of protection works and soil conservation. The different level of protection measures resulted in substantial reduction of humus and nutrient losses from the soil in the watersheds of the rivers Kalimanska Reka and Jasenica compared to the losses in the watersheds of Dubosnički Potok and Djurinovac Potok.

In addition to the impacts of water erosion, great losses of humus and nutrients are also the result of wind erosion. Tbe assessment based on the above research show that in Serbia water and wind erosion cause great losses of humus and biogeneous elements, which affects agricultural production.

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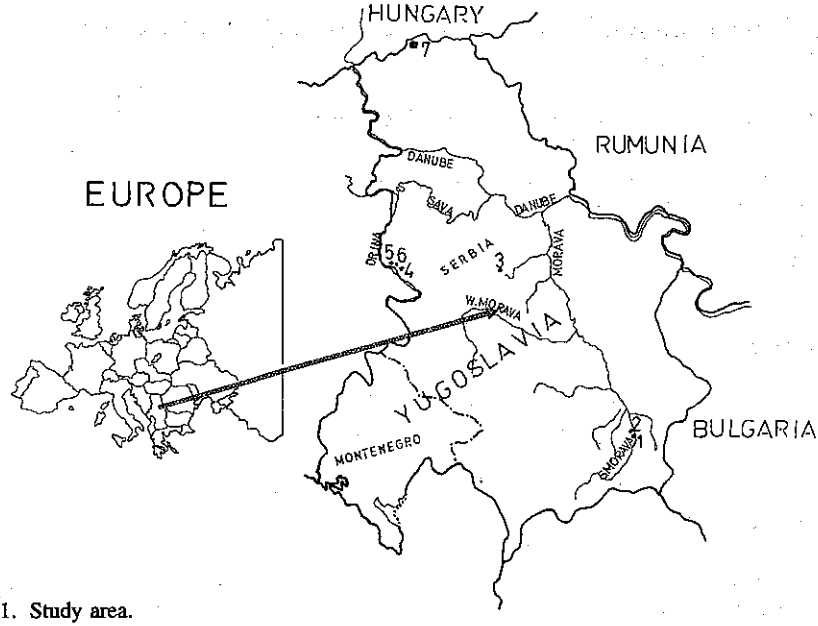

Fig. 1. Study area.

SOME PROBLEMS OF MINIMUM TILLAGE IN THE CHERNOZEMIC ZONE OF RUSSIA

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ABSTRACT

Field experiments were conducted to evaluate the effect of reduced (minimum) tillage practices on weed control and crop yields in the Chernozemic Zone of Russia.

INTRODUCTION

In a practical sense, soil tillage operations are aimed at three goals:
- managing soil properties;
- improving weed, disease and pest control;
- advances in crop productivity.

The specific soil and climate properties in the Chernozemic zone affect both tillage system forms and the issue as to the named goals.

In the Central Chernozemic zone of Russia chernozems present about 80 % of croplands. Soils are usually sufficiently moistened in late autumn and deeply frozen in winter. In spring melting snow provides a large amount of snow water, increasing water erosion processes. The problem of weed infestation is critical.

Under these conditions there arises a problem: whether such particular properties would match well with reduced tillage adoption.

MATERIALS AND METHODS

Field experiments have been conducted within the last 7 years on typical and leached chernozems with humus content of 3.7 % and above. Conventional tillage with mouldboard ploughing (20-22 cm) and reduced tillage systems were studied. The reduced tillage systems comprised several (2 or 3) successive shallow treatments with or without intercropping. Major crops planted were winter wheat, sugar beat, barley, spring wheat and annual grasses.

RESULTS AND DISCUSSION

Our research data (3) indicate that with chernozems it is not necessary to regulate some of their physical properties and in the first instance it concerns their density. It is to be related to their inherent physical properties that chernozems become uncompactable when the moisture content in an arable layer increases to the value of minimum water capacity. Thus moistened at least once a year, what happens during spring snowmelting as a rule, the soils acquire aggregate density ranging from 1.0 to 1.25 g/cm^3 and provide optimal environment for cultivated plants. Thus, in the Chernozemic region, tillage operations within 80 % of the overall arable land can be neglected as a foremost factor in maintaining agrophysical properties of the soils (2). The rest of the cultivated area, summing to 20 %, is occupied by other types of soils, for example grey forest soils, having a smaller content of humus as compared with chernozems. Regulation of physical properties is essential for these soils. Special emphasis is laid on tillage systems increasing humus content in the soils (4). In this respect special attention is given to tillage forms which concentrate crop residues on the surface or near the surface especially when they are combined with organic matter application. Such tillage forms promote soil moisture conservation and humus formation processes versus humus mineralization.

Weed control as a soil tillage related function is the second point to be discussed. Conventional tillage is the most widely adopted tillage system in the Chernozemic zone. Mechanical and chemical methods of weed control including scuffing and disking operations which precede ploughing do not eliminate weeds since for decades arable layers throughout their depth have been saturated with seeds and other reproductive parts of weeds. Thus, irrespective of the way arable layers are turned over, germinative seeds of previous growing seasons would be found at the surface and weed seeds of a current year would be ploughed down. When soil is roughly tilled and autumn is dry, weeds do not germinate in autumn. But in spring they emerge and infest fields. When in autumn the moisture amount is sufficient for germination, ploughed fields are overgrown with weeds. An intensive autumn/winter season could freeze summer weeds, but overwintering and perennial weeds perserve their germination. So, plowing does not solve the problem of weed control in the Chernozemic region.

Our experiments show that surface soil tillage is a more effeetive alternative to plowing, because it provokes favourable conditions for an accelerated emergence of weeds in autumn and when a part of weeds has sprouted mechanical cultivation is used to eliminate weeds. Provocation works well with soil loosening at a depth of 8 to 10 cm and successive soil surface ramming. These tillage practices provide aggregate soil structure and if there occurs even a small amount of rainfall, about 5 to 7 mm, weed germination is prompted. Shallow tillage in various forms associated with ramming embodies the effects of eliminating weeds and facilitating emergence of new ones. The use of surface tillage combined with intercropping resulted in 2 times less amount of perennial weeds detected at the beginning of the next growing season (Table 1).

Table 1. Effects of tillage practices and intercropping of infestation of spring wheat, average of 1989-91.

Tillage practices	Weed number at the beginning of a vegetational season (per m^2)	
	Total	Perennial weeds
Ploughing at 20-22 cm	48.9	4.0
Soil loosening (2-3 times) at 8-10 cm	40.4	2.3
Soil loosening (2-3 times) at 8-10 cm + intercropping	31.2	2.0

The use of multiple successive soil tillages at 8-10 cm depth considerably reduces a number of weeds and at the same time does not increase an amount of cereal plants affected by root rot and brown rust. This factor is thought to contribute to minimum tillage adoption.

There is observed insignificant but beneficial effect of surface tillage on the yields of winter wheat and annual grasses. There is no trend to increasing of barley and spring wheat yields, as well as of sugar beet (Table 2).

Table 2. Effects of primary tillage systems on crop yields (average of 1986-1993).

Primary tillage forms	Crop yields (t/ha)				
	annual grasses	winter wheat	sugar beet	barley	spring wheat
Plowing at various depths	6.6	3.5	40.0	4.0	3.1
Successive shallow tillages at 6-8 cm	6.8	3.7	37.0	4.0	3.2
Shallow tillage at 6-8 cm depths + intercropping	6.4	3.7	37.0	4.0	3.0
LSD.95	0.18	0.16	0.30	0.21	0.15

The critical shortcoming of primary reduced tillage lies in an increased erodibility of arable fields and the subsequent development of erosion processes. This negative impact of shallow tillage can be overcome with adoption of soil slitting in autumn, i.e. creation of small trenches inproving the infiltration capacity of soil.

CONCLUSION

In the Central Chernozemic Zone of Russia reduced or minimum tillage forms can be used as primary tillage, and due to genetic properties of chernozems minimum tillage provides the similar environment for cultivated plants as ploughing does. The data show that successive loosening of soil at 6-10 cm associated or not with intercropping improves weed control, but has no evident effect on crop yields.

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CROP ROTATION AND TILLAGE INFLUENCES ON SOIL MOISTURE REGIME IN SEMI-ARID SOUTHERN ALBERTA, CANADA

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ABSTRACT

With the recent adoption of conservation farming systems in Alberta, there has been interest in replacing the fallow phase with alternative crops. However, there is a paucity of information on changes to soil moisture regimes by inclusion of these crops, especially in combination with zero tillage. A study was initiated in 1984 to investigate the performance of winter wheat (*Triticum aestivum* L.) grown under conventional, minimum and zero tillage in monoculture and in two-year rotations with fallow, canola (*Brassica campestris* L.) or lentils (*Lens culinaris* Medic.)/flax (*Linum usitatissimum* L.). Continuous cropping greatly depleted soil moisture reserves, resulting in some crop failures. Yields of winter wheat were directly related to profile soil moisture conditions created by the different rotations. Zero tillage marginally improved profile soil moisture and which resulted in significantly higher wheat yields in one year.

INTRODUCTION

The greatest limitation to the productivity of agricultural soils on the semi-arid Canadian prairies is available soil moisture, which has historically favoured a spring wheat-fallow rotation. Conventional fallow runs the risk of inducing wind erosion since the soil is loosened and dried, and residue is buried by the 2-4 tillage passes required for weed control during the fallow phase. Replacement of spring wheat in a rotation with winter wheat can give some measure of erosion control by providing adequate cover in fall and early spring when soils are particularly prone to wind erosion. These beneficial effects may be enhanced with zero tillage which maintains more available water in the root zone and conserves more crop residue on the soil surface (5).

A recent review of crop rotation studies on the Canadian prairies concluded that winter wheat has not been used for a sufficient time in rotations to allow proper assessment of its potential (1). Introduction of crops such as canola, lentils and flax into rotations with winter wheat has not been adequately studied. These crops could replace the fallow phase of the rotation thus controlling erosion and may use less water than continuous cropping to cereals.

The effects of conservation tillage techniques compared with conventional or minimum tillage have been reported for many studies throughout the Canadian prairies (4). However, most of this information pertains to spring wheat. Data on the performance and moisture use of winter wheat under conservation tillage systems in various crop rotations is lacking (2).

This paper reports on soil moisture regimes of winter wheat under conventional, minimum and zero tillage in two-year crop rotations of winter wheat-fallow, winter wheat-winter wheat, winter wheat-canola and winter wheat-lentils/flax. Winter wheat yields from the study have been reported (3).

MATERIALS AND METHODS

This aspect of the study was conducted between fall 1985 and spring 1991. The experimental site is a Dark Brown Chernozemic soil located at the Agriculture Canada Research Station, Lethbridge, Alberta (49°43'N, 112°48'W). Lethbridge has a mean annual precipitation of 402 mm. The Ap horizon was a sandy clay loam with approximately 1.8% organic carbon. The experiment was devised as a split-plot design with six replications. The main treatment was crop rotation, with tillage system as a sub-treatment. Four two-year rotations were established: winter wheat-fallow, winter wheat-winter wheat, winter wheat-canola and winter wheat-lentils. Flax replaced lentils in 1989. Each phase of each rotation was grown each year. The first winter wheat crop in each rotation was seeded in September 1984 after fallow, spring wheat, canola and lentils.

The sub-treatments were conventional tillage, minimum tillage, and zero tillage. Each sub-plot was 6 x 40 m. For conventional tillage, the seedbed was prepared with one pass of tandem disc, followed by a rodweeder and packers. In the fallow phase of the wheat-fallow rotation, conventional tillage consisted of an initial pass of a wide-blade cultivator followed by a heavy-duty cultivator as required (normally two or three passes) for weed control. For minimum tillage, the seedbed was prepared with one pass of a heavy duty cultivator followed by a rodweeder and packers. Minimum tillage in the fallow phase of the wheat-fallow rotation consisted of wide-blade cultivation as required for weed control. Herbicides were used for weed control in the zero tillage treatment.

Winter wheat was seeded with a hoe drill between September 15 and 30 each year. For the five harvest years (1986-90), four replications of the winter wheat plots were sampled for gravimetric soil moisture in 15 cm increments to 1.5 m depth. The three sampling times were: in fall after seeding, in spring when the wheat was actively growing and after harvest in the fall. The bulk density of each 15 cm increment was calculated from the soil dry weight/volume of the sampling tube in order to estimate total profile water content. Winter wheat grain yield, as well as yields of canola, lentils and flax were measured from 1986-90.

RESULTS AND DISCUSSION

The drier-than-normal weather conditions during the study period compounded the effects of continuous cropping on soil moisture regime. Precipitation for the crop year (August 1-July 31) was 58.7% of normal in 1987/88. Precipitation during the critical establishment period (September 1-October 31) was about twice normal in 1985-87 but about 66% of normal in 1988 and 1989. Precipitation during the second growth phase (April 1-June 30), when yield components are set, was below normal in all five study years, the driest being 1988 at 42.4 % of normal.

The fall sampling after winter wheat seeding indicated that the winter wheat-fallow plots had a major moisture advantage compared with continuously cropped rotations (Figs. 1a, 1b, 1c, 1d, 1e). This advantage was most apparent later in the study (1987-89) as the moisture depletion by continuous cropping was not replenished due to inadequate rainfall. By 30 September 1987, soil moisture content under the winter wheat-fallow rotation was higher than the other rotations at all depths to 1.5 m (Fig. 1c).

The extraction of moisture by the preceding crops (continuous winter wheat, lentils/flax and canola) may also be compared at this sampling time. In 1985, canola extracted much more moisture than continuous winter wheat or lentils (Fig. 1a). In fall 1986, the continuous winter wheat extracted most moisture, followed by canola and lentils (Fig. 1b). This follows the productivity of the crops in the previous growing season. In 1986, winter wheat yielded 2.4 t ha^{-1}, and canola 0.45 t ha^{-1}, while the lentils performed poorly and were desiccated on 22 August. In fall 1987, the continuous winter wheat plots had higher soil moisture content to about 45 cm depth than the winter wheat-canola or winter wheat-lentils plots (Fig. 1c). The winter wheat was harvested on August 10, while the canola and lentils were not harvested until September 10. About 63 mm of rain fell in the intervening period which was not utilized on the continuous winter wheat plots. The winter wheat seeded into the lentils plots had drier soil conditions than that seeded into the canola plots as the lentils produced a respectable yield that year (2.1 t ha^{-1}), while the canola was plots were reseeded to barley on 25 June.

In fall 1988 (Fig. 1d), the canola plots were extremely dry, since a canola crop was harvested although yields were very low (0.05 t ha^{-1}). Due to severe drought and hence poor performance the lentils plots were desiccated on July 20. This created a partial fallow situation and the lentils plots were consequently quite moist to about 90 cm depth and wetter than the fallow below 105 cm. The continuous winter wheat plots were dry to about 70 cm but soil moisture increased below this depth although the profile was still drier than that after lentils. In 1989, all preceding crops to winter wheat were harvested and yields were fairly respectable. Continuous winter wheat yielded 1.24 t ha^{-1}, canola 0.67 t ha^{-1} and flax 0.72 t ha^{-1}. The depletion of moisture by these crops was of the order canola > winter wheat > flax (Fig. 1e).

Soil moisture conditions on the winter wheat plots in the spring of each year are shown in Figs. 1f, 1g, 1h, 1i and 1j. Trends bear a close resemblance to those in the previous fall. Most treatments show some recharge over the winter period, especially the continuously cropped treatments. The moisture trends were reflected in winter wheat yields (Table 1). The continuous wheat plots showed the driest profile conditions in spring 1987 (Fig. 1g) which contributed to significantly lower yields on this treatment (Table 1). Moisture contents in the 0-50 cm layer in spring 1988 (Fig. 1h) were of the order winter wheat-fallow > continuous winter wheat > winter wheat-canola > winter wheat-lentils which mirrored yields of 1.45, 0.55, 0.4 and 0.15 t ha^{-1} respectively (Table 1). Similar relationships between soil moisture and yield were apparent in 1989 (Fig. 1i and Table 1). Winter wheat stands were so poor as a result of dry soil conditions after canola in 1988 that these plots were reseeded to spring wheat in 1989 to prevent soil erosion.

After harvest all profiles were essentially equalized with respect to soil moisture especially at shallower depths. Rainfall between harvest and fall sampling allowed some recharge to about 30 cm depth especially in 1986 (Fig. 1k), 1987 (Fig. 1m) and 1989 (Fig. 1o). However, there was evidence of residual moisture carryover on the winter wheat-fallow plots in 1987. Even though this treatment produced highest grain yields (Table 1), its profile contained the most soil water to 75 cm depth after harvest (Fig. 1m).

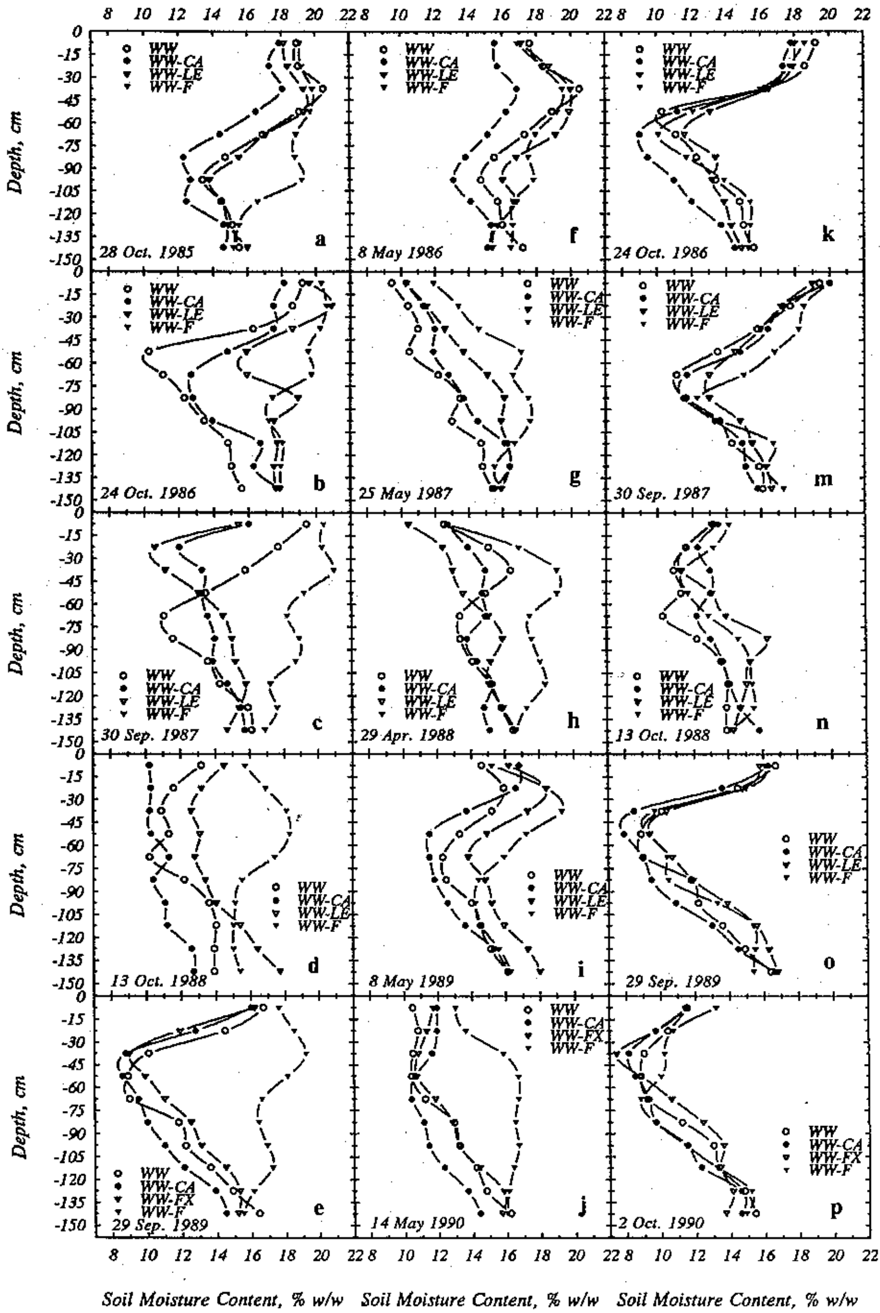

Fig. 1. Effect of winter wheat rotation on soil moisture regime: (a-e) after seeding; (f-j) the following spring; (k-p) after harvest. (WW = winter wheat; CA = canola; LE = lentils; FX = flax; F = fallow).

Table 1. Effect of crop rotation on winter wheat yields (t ha^{-1}). Within years values followed by the same letter are not significantly different (LSD, $P \leq 0.05$).

Rotation	1986	1987	1988	1989	1990
Continuous winter wheat	2.40*b*	1.47*b*	0.55*b*	1.24*c*	0.55*c*
Winter wheat-canola	2.50*b*	2.47*a*	0.40*b*	-	1.31*b*
Winter wheat-lentils/flax	2.49*b*	2.58*a*	0.15*c*	1.75*b*	1.12*b*
Winter wheat-fallow	2.92*a*	2.63*a*	1.45*a*	2.27*a*	2.19*a*

The effect of tillage treatment (averaged over all four rotations) on total profile soil moisture content at 17 sampling times is shown in Table 2. Tillage effects on soil moisture regime were much smaller than rotation effects.

Table 2. Effect of tillage system (averaged over four rotations) on total profile soil water, cm, to 1.5 m depth. (Values within rows followed by the same letter are not significantly different (LSD, $P \leq 0.05$).

Sampling Time	Date	Conventional	Minimum	Zero
After seeding	28 October 1985	43.9*a*	42.3*a*	43.9*a*
Spring	8 May 1986	41.0*a*	40.5*a*	40.9*a*
After harvest	24 October 1986	39.1*a*	38.0*a*	40.2*a*
After seeding	24 October 1986	46.5*a*	46.4*a*	47.8*a*
Spring	25 May 1987	37.9*b*	38.8*ab*	40.9*a*
After harvest	30 September 1987	41.9*a*	41.8*a*	42.0*a*
After seeding	30 September 1987	43.3*a*	41.7*a*	41.9*a*
Spring	29 April 1988	41.2*a*	39.5*ab*	38.2*b*
After harvest	13 October 1988	35.7*a*	34.3*ab*	32.8*b*
After Seeding	13 October 1988	35.2*a*	32.5*b*	35.2*a*
Spring	8 May 1989	42.4*a*	40.7*a*	39.2*a*
After harvest	29 September 1989	33.1*a*	31.9*a*	32.5*a*
After seeding	29 September 1989	34.3*a*	34.1*a*	34.7*a*
Spring	14 May 1990	30.6*a*	30.5*a*	29.6*a*
After harvest	2 October 1990	27.0*a*	24.3*b*	25.4*ab*
After seeding	2 October 1990	30.7*a*	30.5*a*	30.0*a*
Spring	23 April 1991	30.4*a*	30.4*a*	32.2*b*

Tillage significantly affected profile soil moisture content at six of the 17 sampling times. Of these, only two showed significantly higher moisture content under zero tillage compared with conventional tillage. These were both spring samplings (25 May 1987 and 23 April 1991, Table 2) and may indicate the snow-trapping capability of standing stubble on the zero tillage treatment. The higher soil moisture on the zero tillage in May 1987 translated in to a significantly higher yield (2.54 t ha^{-1}) compared with conventional and minimum tillage (2.16 t ha^{-1}). The drier-than-normal conditions that occurred during the study exacerbated soil moisture depletion by continuous cropping as illustrated by the declining amounts of profile soil water at seeding time as the study progressed (Table 2). Profile soil water was 46.5 cm on the conventional treatment after seeding in fall 1986. By seeding time in fall 1990, this value had fallen by 35% to 30.4 cm.

CONCLUSIONS

Since this study was conducted over a drier-than-normal period, our results indicate that inclusion of a fallow year greatly enhances production, especially after several dry years. This supports the conclusions of a major review of historical rotation data from the prairies which maintained that summer fallow remains a legitimate option in the cropping systems of western Canada, though its role and recommended use vary with edaphic and climatic factors (1). The use of zero tillage has been recommended as a viable management practice for crop production in southern Alberta (4) for both erosion control and moisture conservation. Under the conditions of this study, the moisture-conserving advantages of zero tillage were only obvious at spring sampling time in two years, likely as a result of increased snow-trapping by the standing stubble on these plots over the winter period.

Due to the dry conditions, the alternatives to fallow (canola, lentils and flax) performed poorly. Nevertheless, we are reluctant to conclude that rotating winter wheat with these crops is not feasible. These crops are justified, provided they can be successfully established, and especially if prevailing precipitation patterns return to the long-term average. There was some evidence that canola may extract more moisture to deeper depths than either winter wheat or lentils or flax which may impede the following winter wheat crop.

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SUSTAINABLE CROP PRODUCTION ON AEOLIAN SANDY SEMI-ARID SOILS IN SOUTHERN AFRICA

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ABSTRACT

Large areas of the soils under rainfed crop production in the semi-arid climatic regions of Southern Africa are of aeolian origin with a sandy texture. These soils are prone to wind erosion, soil compaction and drought, which hamper sustainable crop production.

Field experiments were conducted over three years in which 3 tillage practices were combined with 3 cropping practices. The tillage practices were: i) conventional mouldboard ploughing and ii) stubble mulch tillage, both in combination with deep ripping and controlled traffic, and iii) no-tillage with chemical weed control. Every tillage practice was combined with cropping practices viz. i) continuous maize and ii) wheat with a 5-month fallow and (ii) maize and wheat in rotation allowing a 10- month fallow.

It was found that continuously grown maize and wheat with conventional tillage gave the highest rainfall use efficiency. Conventionally grown maize and wheat in rotation, with a longer fallow, gave the highest whereas no-tillage continuous maize and wheat the lowest yields. The yields on stubble mulching were lower than that on conventional tillage.

INTRODUCTION

Large areas of Southern Africa are covered by aeolian sand deposits with a silt plus clay content lower than 10%. The natural vegetation on these soils is savanna grassveld with shrubs. In South Africa alone about 1.5 million ha of these soils are cultivated for rainfed crop production. The main crops are maize (*Zea mays* L.), wheat (*Triticum aestivum* L.) and groundnuts (*Arachis hypogaea* L.) with conventional mouldboard plowing and seedbed preparation with tine cultivators as the main tillage practice. This practice has led to severe wind erosion and the formation of tillage induced compacted layers just below the plough layer at 0.25 m. This subsoil compaction results in shallow rooting and consequent inefficient utilization of plant available water and nutrients in these deep soils, which have an average rooting depth of 2 m (1). The low average annual rainfall of 450 to 550 mm and high annual evaporation of 2000 to 2500 mm result in severe crop water stress in most seasons. The introduction of stubble mulching as a conservation tillage practice against wind erosion resulted in epidemic plant disease problems like cob rot (*Diplodia zea*) in maize and root rot (*Gaeumannomyces graminis*) in wheat.

It was argued that the sustainability of crop production on these sandy soils could be improved with the introduction of the following measures to solve or alleviate the effect of the detrimental factors. The protection of the soil surface by a plant residue mulch of preferably standing stubble, effectively reduces the wind speed and erosion. Subsoil compaction can be alleviated by deep ripping and controlling implement wheel traffic to fixed parallel lanes (2). The damaging effect of mid season droughts and more severe seasonal droughts on crop yields can be alleviated by allowing a longer fallow period between harvesting of the previous crop and the planting of the next crop. This practice allows storage of more rainfall in the soil, which buffers the crop against drought during the growing season. The risk of crop damage by plant diseases associated with stubble mulching can be reduced by planting, in rotation, crops that are not attacked by the same diseases.

The objective of this study was to test these possibilities of increasing the sustainability of crop production on sandy soils.

MATERIALS AND METHODS

Soils:
The parent material of the soil is aeolian deposits. The texture is fine sand with a clay content of 6% in the topsoil, increasing to 16% at a depth of 1 m and 22% at a depth of 1.8 m. A dense clay layer occurs at a depth of 1.8 m which retards water percolation. A shallow perched water table can develop in wet years. The structure is apedal and the colour yellow brown.

The soil is classified as an Avalon Soil Form Kameelbos Family (3) or Plinthic Quartzipsamments (4). The plant available water capacity increases from 80 mm m^{-1} in the topsoil to 120 mm m^{-1} at 1.8 m. The well rounded and poorly graded particle size distribution allows the soil to yield under low pressures and under gravity during wet conditions, forming high strength layers that retard, and in severe conditions, prevent root elongation. The high permeability of the sandy topsoil and flat topography result in little or no runoff during heavy rains.

Treatments:
The treatments consisted of 3 tillage practices combined with 3 cropping practices to give a total of 9 treatments each replicated twice in a randomized block design. The tillage practices were: i) conventional mouldboard ploughing plus deep ripping as primary tillage operations and a rodweeder on a controlled wheel traffic system for secondary weed control and seedbed preparation, ii) stubble mulch tillage with deep ripping as a primary tillage operation and a rodweeder on a controlled wheel traffic system for secondary weed control and seedbed preparation and iii) no-tillage with chemical weed control. All of these tillage practices were combined with the following cropping practices: i) continuous maize in an annual monoculture system with a 5-month fallow period, ii) continuous wheat in an annual monoculture system with a 5-month fallow period and iii) maize and

wheat crop rotation with one summer maize and one winter wheat crop every 3 years on the same plot allowing for a 10- to 12-month fallow period. Three plots of this treatment in different phases were needed in the experiment to enable comparison of short with long fallow wheat and maize every season.

Maize (cv. PNR 6479) was planted in 2 m rows at a population of 17000 plants per hectare in mid November each year and harvested in June the next year. Fertilizer N and P were applied at 35 kg N and 15 kg P ha^{-1}. Wheat (cv. Tugela) was planted in 0.5 m rows at a seeding density of 25 kg seed ha^{-1}. Fertilizer was applied at 25 kg N and 12,5 kg P ha^{-1}. The wheat was planted in May and harvested in November the same year.

Measurements:
The soil water content was measured with a neutron probe using access tubes installed in each plot to a depth of 3 m. Readings were taken at 0.3 m depth intervals every 2 weeks during the growing season and every 4 weeks during the fallow period. Rainfall was measured using gauges. Total dry matter was harvested at the end of the season and measured.

The efficiency with which rainfall was converted to crop production or the rainfall use efficiency (RUE), was calculated using the equation:

$$RUE = \frac{Y}{R_f + R_{gs} - \Delta W} \tag{1}$$

where RUE = rainfall use efficiency (kg ha^{-1} mm^{-1})
Y = seed yield (kg ha^{-1})
R_f = rainfall from harvesting to planting during the fallow period (mm).
R_{gs} = rainfall from planting till harvesting during the growing season (mm).
ΔW = change in profile water content between harvesting of the previous crop and harvesting of the present crop over a depth of 1.2 m (mm), increase (+) and decrease (-).

Low RUE values indicate high evaporation and/or percolation losses during the fallow period or a poor rainfall distribution during the growing season resulting in crop damage by drought.

RESULTS AND DISCUSSION

The results reported in this paper are for the three years 1990 to 1993.

Seed yield:

The seed yields for maize and wheat for the different tillage practices and lengths of fallow are presented in Tables 1 and 2.

The maize yield varied between seasons due to large differences in the total seasonal rainfall and rainfall distribution during the growing season. The total rainfall during the growing season was 499 mm (poorly distributed, late onset), 77 mm (well distributed) and 165 (well distributed) for the 1990-91, 1991-92 and 1992-93 seasons respectively. The relatively high rainfall during the 1990-91 growing season fell too late to make a significant contribution to the crop yield and 1991-92 was a very dry season. In all the years significantly better yields were obtained with conventional tillage with a long fallow period compared to no-tillage with continuous maize which gave the lowest yields. The conventional tillage practice outyielded the conservation stubble mulch tillage in all the years by an average of 28% for both the 5- and 10-month fallow periods and no-tillage by about 55%. A crop rotation system with a longer fallow period increased the maize yields by between 34 and 40% for conventional and stubble mulching and up to 80% for no-tillage.

Table 1: Mean maize seed yields (kg ha^{-1}) tillage practice and fallow length (months)

Year	Conventional		Stubble mulch		No-tillage		
	5	10	5	10	5	10	$LSD_{0.05}$
1990-91	1625	2450	792	1661	532	1984	1888
1991-92	1171	1481	805	1134	712	546	628
1992-93	2898	3699	2732	3277	1803	2989	1568
Average	1898	2543	1443	2024	1016	1840	
	2220		1733		1428		

Table 2: Mean wheat seed yields (kg ha^{-1}) tillage practices and fallow length (months)

Year	Conventional		Stubble mulch		No-tillage		
	5	10	5	10	5	10	$LSD_{0.05}$
1990	1047	1685	1226	1534	585	990	734
1991	2451	2458	1873	2184	1828	2362	376
1992	611	1036	592	944	583	649	n.s.
Average	1370	1726	1230	1554	999	1334	
	1548		1392		1166		

Wheat production is almost solely dependant on stored water with very little rainfall during the winter growing season. The yield differences and responses to the treatments are mainly the same as for maize. Conventional tillage gave the highest and no-tillage the lowest yields.

Rainfall use efficiency (RUE):
The RUE of summer crops is mainly determined by the rainfall distribution and will vary much between seasons as can be seen from Table 3 for maize. The RUE for wheat is presented in Table 4. Conventional tillage practices gave the highest RUE and no-tillage the lowest for both maize and wheat. As can be expected the shorter 5-month fallow period with a smaller possibility of evaporation and percolation losses resulted in higher RUE values during the dry 1991-92 maize and wet 1992 wheat seasons.

Table 3: Mean rain use efficiency (RUE, kg seed ha^{-1} mm^{-1}) for maize tillage practices and fallow length (months)

				Conventional				Stubble mulch				No-tillage			
		R_f		5		10		5		10		5		10	
Year	R_{gs}	5	10	ΔW	RUE	ΔW	RUE	ΔW	RUE	ΔW	RUE	ΔW	RUE	ΔW	RUE
1990-91	499	67	381	+10	2.92	+35	2.90	+5	1.41	+33	1.96	+8	0.95	+33	2.34
1991-92	77	116	626	-49	4.84	+24	2.18	-48	3.34	+23	1.67	-9	3.52	+9	0.79
1992-93	165	129	198	+9	10.17	-4	10.08	+16	9.83	-13	8.72	0	6.13	-1	8.21
Average					5.98		5.05		4.86		4.12		3.53		3.78

Table 4: Mean rain use efficiency (RUE kg seed ha^{-1} mm^{-1}) for wheat tillage practices and fallow length (months)

				Conventional				Stubble mulch				No-tillage			
		R_f		5		10		5		10		5		10	
Year	R_{gs}	5	10	ΔW	RUE	ΔW	RUE	ΔW	RUE	ΔW	RUE	ΔW	RUE	ΔW	RUE
1990	56	331	379	-32	2.50	-106	3.11	-27	2.96	-114	2.79	-32	1.40	-65	2.48
1991	149	56	541	+24	13.54	-35	3.39	+38	11.22	-19	3.08	+33	10.63	-39	3.24
1992	129	124	193	+12	2.54	-31	2.93	+14	2.48	-15	2.80	+20	2.50	+9	2.07
Average					6.19		3.14		5.55		2.89		4.01		2.60

These results emphasize the contradiction between conservation practices and economic realities. Conventional tillage practices, especially when combined with a longer fallow periode, have the highest risk for wind erosion but it gives the highest yields. No-tillage in a monoculture situation is not economically feasible on these soils and can therefore not be recommended to farmers but it is a possibility in a crop rotation system. The reason why stubble mulching gave lower yields than conventional tillage must still be solved but it was, from visual observations, very effective in preventing wind erosion. Longer fallow periods increased the yields although not statistically significant. Little emphasis can be placed on the absence of statistical differences in these experiments because only two replications were used. This benefit must be compared to the fact that only two crops can be grown in three years with this long fallow practice.

CONCLUSIONS

Lower wheat and maize yields are obtained with the conservation tillage practices compared to conventional tillage. There is therefore no yield or financial incentive for farmers to adopt conservation tillage practices.

Seed yields were improved with a crop rotation programme of maize and wheat allowing for longer fallow periods and a small risk for crop diseases. There is therefore a need for more disease resistant varieties of crops to increase the sustainability of crop production with conservation tillage practices.

Stubble mulch tillage combined with deep ripping, controlled wheel traffic and a crop rotation system on deep sandy soils, with a clay content lower than 10% and a high wind erosion and soil compaction susceptibility, is sustainable in terms of soil and water conservation but will be less economical than conventional tillage practices in a monoculture or crop rotation system.

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AGROECOLOGICAL APPROACHES TO SOIL TILLAGE AND MOISTURE ACCUMULATION IN SEMI-ARID STEPPE ZONE OF THE NORTHERN KAZAKHSTAN

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ABSTRACT

The equation of primary soil tillage for semi-arid steppe zone conditions has been developed which allows to optimize the principal parameters of tilled layer for soils of different texture.The following indices are used in the equation: tillage depth,depth and density of snow cover,thawing water infiltration soil bulk density,water capacity of the tilled layer and soil moisture at tillage time.

The method of calculating the ecological balance between the snow accumulation potential and the technological parameters of the tilled soil layer has been worked out which includes the combination of subtillage and additional reclamative deep tillages adjusted to the slope horizontals with the variable spacing between the passes of reclamative implement and provides the full absorption of melt water.

INTRODUCTION

The intensification and the stabilization of the grain production in the semi-arid steppe zone of the Northern Kazakhstan is inseparably associated with the improvement of soil tillage system.The large diversity of soil types and subtypes and textural variety are demanding the subsequent search of new scientific solutions on working out the differentiated approach to the soil tillage in the region and to the usage of new soil tilling implements and machines.

One of the main requirements to the soil tillage technology is the ability to accumulate autumn and winter water and to retain it in the period of spring snow melting (Barayev,1975; Bakayev, 1975).This statement is confirmed by the results of foreign researchers who reported that the only advantage of autumn stubble tillage was the improvement of the thawing water absorption by soil in the years with wet autumn when as a result of freezing the upper soil layers saturated with moisture the absorption of melting water was becoming worse (John, Adams, Hanks,1964).

We believe that the study of physical,water-physical and physical-mechanical properties of arable and subsurface soil layers in interrelation with agroclimatic conditions should be taken as the basis of soil tillage technological solutions. It allows to develop the agrophysical model of arable layer taking into account the optimization of the principal parameters of the tilled soil layer and the ecological orientation of soil tillage as a whole.

The objective of this study was to develop the methods of optimizing the technological parameters of the primary soil tillage taking into account the microclimatic peculiarities of semi-arid steppe agrolandscape of the Northern Kazakhstan.

MATERIALS AND METHODS

This investigation included the laboratory and laboratory-field experiments to study the physical and water-physical properties of southern calcareous chernozem of different texture.

Soil samples with disturbed and undisturbed structure were analysed. The selected soil samples were separated into different fractions by the dispersion method, and then the following indices were determined: the bulk density by Kachinsky method (1965), moisture capacity (maximum, capillary, total), water permeability by Kaurichev (1980). Agrotechnical experiments were laid out to take the samples with undisturbed structure as applied to the evaluation of different soil tillage implements.

When evaluating the agrolandscape the topographic levelling was made, the snow cover depth, soil moisture and melting water intake were measured under natural conditions.

RESULTS AND DISCUSSION

Our study shows that during spring snow melting by the time of snow being melted the depth of soil thawing out on the fallow field was 5-10 cm and on the stubble land-down to 35 cm. Moreover the thawed out layer of soil has the abundant amount of moisture filling all the pores and forming the puddles of water on the field surface. At this time the moisture content in the arable layer is about 60-65%, and subsequently as the soil being thawed out the moisture goes down to the deeper layers and partially it is lost by evaporation.

The water penetration into deeper horizons of frozen soil below the tilled layer is very limited. This is because the capillary pores are partially filled with ice and the amount of noncapillary pores in the untilled layer is not large.

Considering this circumstance the soil tillage should create such structure of arable soil layer which would provide the absorption of total volume of melting water in the tilled soil layer. Thereby the part of water penetrates into free capillary pores and is described by the index of capillary moisture capacity (W_k), the other part fills bigger noncapillary pores (W_n) and both parts put together give the water capacity of the tilled layer (W_o)

$$W_k + W_n = W_o \text{ ,mm}$$

The results of the laboratory experiment showed that when increasing the sizes of soil fractions soil bulk density and the capillary moisture capacity are decreasing but the values of maximum water capacity are growing (Table 1).

Table1.The change of water-physical characteristics of chernozem soil with different texture as affected by size of fractions

No	Fraction size,mm	Sandy loam chernozem			Loamy clay chernozem		
		BD	CMC	MWC	BD	CMC	MWC
1.	Sample of natural structure	0,90	24,6	29,7	1,03	34,1	40,9
2.	< 0,25	0,80	30,9	32,9	0,91	39,4	39,8
3.	0,5-0,1	0,80	31,2	34,0	0,86	37,3	43,4
4.	1 - 2	0,74	23,8	36,3	0,84	38,3	43,8
5.	3 - 5	0,70	21,2	36,1	0,74	35,7	47,0
6.	5 - 10	0,70	21,2	36,5	0,69	34,0	46,0
7.	10-30	0,67	19,3	34,9	0,67	33,5	46,6
8.	30-50	0,59	19,8	37,1	0,70	33,7	51,9
9.	> 50	0,59	22,2	37,3	0,68	33,2	45,9

BD - bulk density,g/cm^3
CMC - capillary moisture capacity,%
MWC - maximum water capacity,%

When analysing the soil samples with undisturbed structure taken in the natural conditions in the field cultivated by various soil tillage implements it was found out that their influence on the change of water-physical properties of arable layer is different (Table 2).

Table 2.The change of water-physical characteristics of loamy clay chernozem as influenced by soil tillage

No	Treatment	Indices				
		Soil layer, cm	BD g/cm^3	CMC %	MWC %	Water permeability per 1 min,mm
1.	Virgin land	0-10	1,17	34,1	37,3	0,080
		10-20	1,34	29,7	31,9	0,020
		20-30	1,29	30,6	32,6	0,004
2.	No autumn tillage	0-10	1,06	36,9	39,6	0,050
		10-20	1,22	35,2	37,5	-
		20-30	1,28	34,7	38,9	-
3.	Cultivation to 12-14 cm	0-10	1,04	38,9	44,5	0,040
		10-20	1,14	37,8	40,7	0,002
		20-30	1,18	37,5	41,9	0,002
4.	Subsoiling to 25-27 cm	0-10	0,96	43,0	48,7	0,210
		10-20	0,97	40,0	43,7	0,070
		20-30	1,05	40,1	44,0	0,008
5.	Chiselling to 25-27 cm	0-10	0,99	39,9	46,6	0,150
		10-20	1,03	44,6	46,0	0,030
		20-30	1,06	38,8	42,7	0,007

Soil tillage accomplished by various equipment allows to change physical properties of arable layer.

Subsoiling to 25-27 cm increases the soil water permeability several times and water holding capacity by 10-20%, lowers the value of bulk density. As a whole the water-physical characteristics of arable layer have been improved by deep soil tillage.

The comparative characteristics of physical-mechanical properties of soils under study show the increase of hygroscopic and as a consequence, unavailable moisture when the soil texture being heavier (Table 3).

Table 3. The change of physical-mechanical properties of chernozem soil

No	Soil type	Indices		
		Hygroscopic moisture, %	Maximum hygroscopicity, %	Plasticity number
1.	Southern calcareous sandy loamy chernozem	1,5	3,6	9,8
2.	Southern calcareous loamy clay chernozem	3,1	6,5	14,0

Moreover, the higher values of plasticity number in the heavy textured soils determine the wider range of moisture adequate for soil tillage.

For the purpose of creating no runoff conditions by the mechanical soil tillage the water capacity of the tilled layer (the volume of free pores) should have the value equal to the total water storage in snow, determined as the product of snow depth and its density

$$W_o = T \cdot d ,$$

where:
T - snow depth, cm;
d - snow density, g/cm³.

Thus on the heavy textured soils with poor water permeability the water capacity of arable layer is the function of the volume of free pores, depending on the depth of tillage and the intensity of loosening the arable layer by tillage

$$H = 70 \frac{T \cdot d}{(W_o - W)\ (2 - V)} , \qquad (1)$$

where:
H - the depth of autumn soil tillage, cm;
T - snow depth, cm;
d - snow density, g/cm³;
W_o - water capacity of the tilled soil layer, %;
W - soil humidity at tillage time, %;
V - bulk density, g/cm³.

On the light textured soils as well as on the loose soils with high humus content (over 5%) the filtration of thawing water bellow the tilled layer is going on during the snow melting in spring.Thereby with the reducing of soil moisture level prior to winter the water infiltration in spring is growing up because of larger amount of free pores,and to a great extent because of cracking of arable and subsurface soil.

In this case the equation is as follows

$$H = 70 \frac{(T \cdot d)\ (1 - \delta)}{(W_o - W)(2 - V)}\ , \text{ where} \tag{2}$$

δ - the coefficient expressing the infiltration (I) of melt water by frozen soil below the tilled layer and determined as the ratio of infiltration value to total water storage in snow.

$$\delta = \frac{I}{Q}\ , \text{ where} \tag{3}$$

Q - water storage in snow,mm.

On the basis of equation 1 we have made calculations and drew up the nomogram of the change of the necessary tillage depth on the chernozem soil of loamy clay texture as related to water storage in snow ensuring the total absorption of thawing water.

The represented nomogram is accomplished for the treatment by sweep and chisel.The indices of bulk density and maximum water capacity with the first implement and the second one were 0,99 g/cm^3,46%,and 1,1 g/cm^3,42%,respectively.

Several technological approaches can be used for the autumn soil tillage by various implements.First of all,the monotechnological approach when the tillage method is uniform in the whole field and is made by one implement at the certain depth.

Secondly,polytechnological approach when different types of implements are used on one field in various combinations with different tillage depth.For example,the combination of autumn soil tillage with subsoiling or with additional reclamative deep tillage to create no runoff conditions on slopy arable lands in the period of spring snow melting.

For this purpose we have developed the method of calculating the ecological balance between the intensity of snow accumulation and the soil tillage practice for creating the no runoff conditions in spring.

To solve this problem by means of the combination of different kinds of soil tillage on slopy cropland one one should keep the following requirements:in a cross section of the field the product of the strip width with common tillage and the water capacity of the tilled layer summed with the product of strip width with deep tillage and its water capacity should provide the water capacity at the level of water storage in snow. In other words the total water storage in snow should be equal to the sum of modules of water capacity of tilled strips

$$\Delta W + \Delta W_1 = Q \text{ ,where} \tag{4}$$

$\Delta W = S \cdot W$ - module of water capacity of tilled layer after common autumn tillage,mm;
$\Delta W_1 = S_1 W_1$ - module of water capacity of tilled layer after additional reclamative tillage (chiselling subsoiling and others) mm;
S - strip width with common tillage (the width of spacing between the passes of reclamative implement),mm;
S_1 - strip width with reclamative tillage,m;
W and W_1 - water capacity of the tilled layer after general tillage and reclamative tillage,mm.

Proceeding from the cited above relationship the spacing between the passes of reclamative implement is determined by the following equation

$$S = \frac{Q - \Delta W_1}{W} \tag{5}$$

CONCLUSION

The method of calculating the ecological balance between the intensity of snow amelioration and the soil tillage practice has been developed which includes the combination of common and additional strip reclamative tillage on slopy cropland.

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THE EFFECT OF PLOUGHING, DIRECT DRILLING AND MINIMAL CULTIVATION ON DRAINED AND UNDRAINED LAND ON YIELD AND NITROGEN UPTAKE OF CROPS GROWN ON CLAY SOIL, 1979-1992.

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ABSTRACT

Yield and nitrogen uptake of winter crops established by direct drilling or after ploughing were compared on drained and undrained land. Drainage improved yield by 10% overall, the benefit to yield being greater for direct drilled crops (1.12 t/ha/yr) than on ploughed land (0.23 t/ha/yr). Nitrogen uptakes were slightly less on undrained land especially in direct drilled crops. Ploughing previously direct drilled land increased the yield and N uptake of crops but only for 2-3 years. Cover crops took up little nitrate because they did not establish well on the clay soil.

INTRODUCTION

Field drainage is an important factor in the management of heavy soils. We tested the effects of drainage on crops established after ploughing and by direct drilling. Later the yield and nitrogen uptake of different crop sequences were compared on drained land which had previously been direct drilled or ploughed.

MATERIALS AND METHODS

The experiment is located at Faringdon, 32 km southwest of Oxford on a clay soil (Stagnogley) containing 54% clay and 32% silt. The soil, site and drainage design were reported by Cannell *et al.* 1984. From 1978 to 1988 (Phase I) the experiment had 10 undrained plots and 10 with intensive secondary drainage comprising clay pipes at 90 cm depth with porous gravel backfill and at 90° to them mole drains at 2 m intervals and 60 cm depth. Each plot was hydrologically isolated and 0.24 ha in area, large enough for farm scale machinery to be used. In the first two years, all plots were tine cultivated to 25 cm depth and in 1980 the tillage treatments were imposed. On both drained and undrained land five plots were ploughed and five direct drilled, giving five replicates of each of the four treatment combinations. Crops were autumn sown; winter wheat was the main cereal with break crops of oats or oilseed rape (Table 1).

Table 1. Crops and fertiliser nitrogen applied (kg/ha) and the amount in aerial biomass at harvest, Phase I, 1981-1988.

		N applied to crop			N recovered in crop				
					Drained		Undrained		
Year/crop[a]		autumn	spring	Total	Plough	Direct Drill	Plough	Direct Drill	SED
1981	Wheat	0	149	149	161	179	165	149	11.9
1982	Wheat	24	148	172	151	166	128	136	5.4
1983	Oats	30	111	141	109	118	103	74	13.9
1984	Wheat	17	223	240	274	262	267	261	12.2
1985	Oilseed rape	46	239	285	262	220	245	210	30.6
1986	Wheat	0	130	130	220	223	233	202	18.6
1987	Oats	0	100	100	144	124	141	121	5.4
1988	Wheat	0	194	194	254	239	239	213	13.2

[a] Autumn sown

Table 2. Treatments, crop yields (85% DM) and N uptakes in Phase II, 1989-1992

	1988/89			1989/90			1990/91			1991/92		
Plot Treatment	Crop	N uptake (kg/ha)	Yield (t/ha)	Crop	N uptake (kg/ha)	Yield (t/ha)	Crop	N uptake (kg/ha)	Yield (t/ha)	Crop[c]	N uptake (kg/ha	Yield (t/ha)
Burn/	Grass	62	3.49	Grass	32	4.30	Grass	17	1.44	Winter	127	4.50
Tine	Ley	108[b]	4.88	Ley	36	4.50	Ley	21	1.83	barley	144	5.23
Burn/	Fallow/	158[b]	3.46	Winter	136	5.31	F.rape/	228	3.84	Winter	267	5.66
Tine	S.wheat	138	2.77	barley	100	4.18	S.beans	262	4.24	barley	250	5.53
Burn/	Mustard/	111	3.22	Winter	105	5.21	Fallow/	264	4.15	Winter	212	6.17
Tine	S.wheat	148[b]	3.53	barley	143	5.83	S.beans	253	4.14	barley	234	5.85
Burn/	Winter	122	5.70	Winter	172	7.64	Winter	187	6.55	Winter	206	5.45
Plough	oats	121[b]	5.96	wheat	182	7.44	wheat	141	5.12	barley	212	5.59
Plough/	Winter	128[b]	6.05	Winter	192	7.32	Winter	215	6.50	Winter	190	5.33
Inc.[a]	oats	120	5.60	wheat	148	7.00	wheat	192	6.37	barley	199	5.53
Burn/	Winter	94[b]	5.88	Winter	170	7.64	Winter	269	3.86	Winter	237	6.03
Tine	oats	93	5.21	wheat	166	7.19	beans	257	3.92	barley	240	6.89

[a] Inc. = Straw incorporated; [b] previously direct drilled in Phase I; [c] all plots ploughed

Phase II of the experiment started in autumn 1988; some of the previously undrained plots were then drained to provide six replicate pairs of plots with different combinations of winter and spring sown crops. Residues from the previously harvested crop were either burnt *in situ* or incorporated, and land was prepared by either ploughing (20-25 cm) or tine cultivation (15-20 cm). One plot of each pair was previously ploughed and the other direct drilled. Treatments and crops for Phase II are given in Table 2. Yields in both Phases I and II were estimated using a plot combine harvester cutting at least 50 m^2 of crop on each plot. Crops were sampled in the spring before nitrogen fertiliser was applied and at maturity to estimate N in aerial biomass.

RESULTS

Crop yield and nitrogen uptake in Phase I

In 1979 a cultivation pan was identified 20 cm below the soil surface; this counteracted the effect of secondary drainage. Sub-soiling disrupted the pan and in 1980 yield on drained land was 7.33 t/ha, 6% greater than on undrained land. Heavier yields were recorded on drained land every year in Phase I except 1986, when the crop establishment and grainfill periods were drier than average. Significantly greater yields occurred on drained land in 1982, 1983 and 1988. In 1982 there was also better root and shoot growth (Cannell *et al.* 1986). The autumn of 1982 was very wet, causing waterlogging especially on undrained land. Similar autumn conditions occurred in 1987 leading to the death of many plants on undrained land in early 1988.

The cultivation comparison initiated in 1980/81 provided eight crop year comparisons of ploughing and direct drilling. Heavier yields were obtained in five years after direct drilling and in three years after ploughing. The three years when crops sown after ploughing yielded more grain (1983, 1985, 1988) followed wet autumns. Direct drilled crops yielded heavier than on ploughed land when autumns were drier, i.e. close to the long-term average rainfall. Interactions between drainage and cultivation occurred in five years but showed no consistent pattern. Drainage benefitted direct drilled crops by a mean of 1.12 t/ha/yr; on ploughed land the benefit was 0.23 t/ha/yr. The increase in yield as a result of secondary drainage was 10% overall and for the five wheat crops it was 7% (Table 3).

Table 3. Mean yields of crops (t/ha/yr) in response to drainage and cultivation, Phase I. P = ploughing; DD = direct drilling.

	Cultivation	Drained	Undrained	SED
All crops	P	7.28	7.05	
	DD	7.46	6.34	0.077
Mean		7.37	6.69	
Wheat crops	P	8.27	8.10	0.079
	DD	8.71	7.79	
Mean		8.49	7.95	

Table 1 gives N uptakes by crops. There was no consistent effect of treatment on nitrogen uptake, but there was generally less nitrogen in crops on undrained land especially where they were direct drilled. No fertiliser nitrogen was applied in autumn in four years and each of these crops at maturity contained nitrogen equal to or greater than the amount applied as fertiliser. When crops received autumn nitrogen uptakes were less than the amount applied except in 1984.

Crop yield and nitrogen uptake in Phase II

In the first two years of Phase II almost all crops growing on land that had been direct drilled in Phase I had heavier yields and greater N uptakes than those on plots previously ploughed. This probably reflects greater mineralisation of nitrogen after the first disturbance by cultivation in eight years. Differences were less in the third year; and at the end of the fourth year plots that had grown cereals in all years showed no differences in total production or uptake of nitrogen related to the previous cultivation practices. In 1988/89 winter cereals yielded heavier than spring cereals sown after a winter fallow or cover crop but in 1990 spring sown beans yielded heavier than winter beans which had established slowly. In 1992 winter barley after winter beans yielded heavier than barley after wheat and both yielded more than barley after unfertilised grass.

Cover crops took up 24 kg N/ha in the autumn of 1988 and 31 kg N/ha in autumn 1990. This represents a saving of nitrogen which might otherwise be lost by leaching. However, in both years the cover crops were difficult to establish and this decreased their effectiveness. On ploughed land with the same winter crop sequences, burning residues or incorporating them did not affect the total amount of grain produced. Burning after tine cultivation produced 6% less grain than burning after ploughing but N uptake was nearly 14% greater.

DISCUSSION

Drainage assists the management of clay soils by improving soil conditions for cultivation and crop growth. In Phase I this increased yield by 10%, an amount similar to that reported by Armstrong (1978). The method of tillage had little effect on drained land, but on undrained land direct drilling did not improve yields especially when the autumns were wet. As crops which received autumn N generally contained less N at harvest than that applied as fertiliser, it is likely that some N was not taken up. Measurements of nitrate leaching under these crops suggested that most of it was lost in drainage (Goss *et al.* 1993).

In Phase II, the yields and N uptakes suggest that crops on land previously direct drilled benefitted from increased mineralisation of organic matter. However the benefit lasted only 2 - 3 years. Cover crops had little or no benefit on the average yield of the spring crop that followed but the winter sown cereal the following autumn did benefit slightly from the cover crop residues. Because the cover crops were difficult to establish they took up less N than autumn sown cereals.

CONCLUSIONS

1. Drainage increased yield of autumn sown crops, by 10% on average. The benefit from drainage was greater on direct drilled land than on ploughed land.

2. Crops after ploughing gave heavier yields than direct drilled crops in three years, all of which followed wet autumns.

3. Where crops received autumn nitrogen, N uptakes at maturity were less than the amount applied as fertiliser. When no autumn N was given, uptakes exceeded N applied in spring.

4. Cover crops took up small amounts of N mainly because of poor establishment. The residual benefits to subsequent crops were small.

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DETERMINATION OF RUNOFF AND ACTUAL EVAPOTRANSPIRATION FROM SITES WITH DIFFERENT SOIL PHYSICAL PROPERTIES

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ABSTRACT

Simulation models calibrated for a representative slope with loess derived soils were used to determine the water balance components for different expositions and slopes in the hilly region south of Hannover (Lower Saxony, Germany). Results of field measurements and simulation studies show that soil water balance is strongly related to slope position and relief. It was found that evapotranspiration at the bottom of a slope is often lower than on top of the slope. On slopes with north exposition actual evapotranspiration decreases with increasing inclination. For slopes with south exposition the opposite reaction has to be expected. Field and simulation studies show that runoff occurs under sugar beet whenever soil is bare or sparsely covered, rainfall intensity is high and topsoil is sealed. However, wheel tracks can contribute more to runoff than interrill areas. Interflow may occur on sites with compacted layers or stagnic horizons. Sensitivity analyses show that this process probably takes place whenever hydraulic conductivity of such a layer is less than 10 cm d^{-1}.

INTRODUCTION

In the past two decades, considerable insight has been gained with respect to factors affecting the water balance of intensively used agricultural soils in Germany. In particular, numerous studies have been conducted to investigate the effects of soil physical properties, soil management and land use on water balance components (Renger et al., 1986; Ehlers et. al., 1981; van der Ploeg et al., 1978).

In general, the models developed in the course of these studies were only valid for plane soil surfaces with vertical water flow. Yet many agricultural regions of Germany present a hilly topography, where interflow and runoff may play an important role in the water balance. Soil layers affecting infiltration, such as surface seals or crusts (runoff) and compacted layers in the subsoil (interflow) have to be considered. Because of the difficulty in accounting for these factors, to date very little information is available with respect to the effect of relief, surface sealing and compacted layers on water balance components, although it would be of importance to obtain a better understanding of these processes in hilly regions (for instance in terms of assessing both vertical and lateral nitrate and pesticide leaching).

Therefore, this study was aimed at developing two-dimensional water models capable of accounting for the above factors. Sensitivity studies in combination with field measurements of runoff were carried out to demonstrate the relative influence of specific slope factors (exposition, inclination) and soil factors (surface sealing, compacted layers) on water balance, with special emphasis on actual evapotranspiration, runoff and interflow.

MATERIALS AND METHODS

Field and laboratory measurements

In the hilly region south of Hannover (Lower Saxony) slope lengths of 100 up to 400 m and and inclinations of 1 to 15% are typical. The soils are characterized by loess depositions of the pleistocene with a thickness of 0.4 up to 2.0 m. On the top and middle positions of the slopes soils are classified as more or less eroded Haplic Luvisols, whereas at the bottom colluvial sediments are dominant. Mean yearly air temperature is about 5.5 C° and in average 730 mm rainfall are registrated in this region.

Field measurements for model calibration and to determine runoff were carried out from 1987 to 1991 on a northerly oriented slope in Adenstedt with a mean inclination of 8% and a length of 200 m, which is representative for this region. The crop rotation was sugar beet (1987, 1989, 1991) and winter wheat (1988, 1990). Runoff and sediment were collected at the bottom of the slope for a 2.0 m wide slope segment with and without wheel tracks. Laboratory measurements consisted in the determination of input parameters required for the models (Ψ-Θ and K-Ψ relationship). Soil water retention curves and saturated conductivity (K_{sat}) were determined following procedures decribed by Hartge and Horn (1989). Hydraulic conductivity near saturation (20-100 hPa) was determined by an instantaneous profile approach using a setup proposed by Plagge (1991). Laboratory experiments with simulated rainfall to determine decrease of seal conductivity as a function of rainfall energy were carried out by applying simulated rainfall (see Roth and Helming, 1992) on sampling cylinders placed into the surface of runoff boxes. Seal conductivity was estimated following the procedure of Bohl and Roth (1993) by measuring the saturated hydraulic conductivity of sealed and unsealed sampling cylinders.

Simulation models

Two two-dimensional simulation models were employed for modelling the water flow. A detailed description of the theoretical assumptions and calibration of the models is given by König (1990) and Wessolek et al. (1992). Briefly, model I uses a numerical multigrid concept which allows for the calculation of vertical and horizontal waterflow for saturated and unsaturated soil conditions of a whole hydrological regime. Furthermore, model I requires a surface sealing factor ß as input which describes the decrease of K_{sat} of the seal as a function of rainfall energy. In model I runoff occurs whenever rainfall intensity overpasses infiltration capacity. For this approach, the topsoil is divided into two layers with a thickness of 2.5 mm (crust) and 50 mm, respectively. The mean hydraulic conductivity of the topsoil with various degrees of surface sealing during the vegetation period was calculated by averaging crust and plough layer conductivity (König, 1990; Wessolek et al., 1992). As such, model I accounts for the effect of surface sealing as a rainfall energy dependent decrease of saturated conductivity. Runoff from top to the bottom is then calculated using the theory of kinematic waves, which is a simplification of the Saint-Venant equations (Woolhiser, 1977). Surface roughness is considered using results of Petraschek (1978) for different soil surface conditions. Model II is a simple two layer model which allows for the calculation of the water balance in the effective root zone only for slope conditions without runoff and interflow. This model considers only the influence of exposition and inclination on actual evapotranspiration and drainage, respectively. Model II has been calibrated for different crops and coniferous forest using values of actual evapotranspiration obtained in field measurements (Wessolek et al., 1992).

RESULTS AND DISCUSSION

In the following section, results of various simulation studies are presented, using either model II (actual evapotranspiration) or model I (runoff, interflow) as calibrated for the loess slope in Adenstedt. The effects of different expositions and slope inclinations on mean actual evapotranspiration are exemplified in Fig. 1 for winter wheat. Northern expositions will reduce evapotranspiration with increasing slope, while the inverse is true for southern expositions. The effect is even more pronounced when the micrometeorological differences are considered. Air humidity is reduced and air temperature is increased at slopes with a southern exposition; the opposite is typical for slopes with northern exposition. This micrometeorological effect increases mean actual evapotranspiration (ETI) further by about 10-20 mm a^{-1}, whereas for slopes with north exposition the opposite can be expected (Fig.1).

Net infiltration capacity is greatly influenced by surface sealing, the latter greatly reducing saturated conductivity in the upper soil layer. In model I, the dynamic process of surface

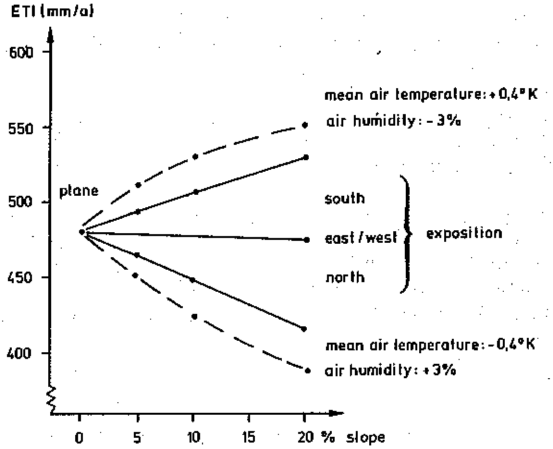

Figure 1: Influence of slope inclination, exposition and micrometeorological effects on mean actual evapotranspiration (mm a^{-1}) of winter wheat on loess soil (model II, without runoff and interflow).

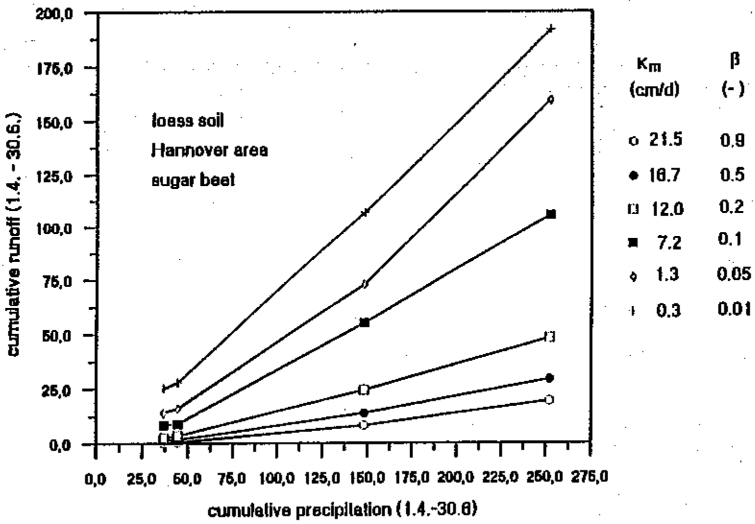

Figure 2: Predicted runoff versus precipitation (mm, cumulated for the period April - June) on a loess soil for various mean hydraulic conductivities and sealing factors ß of the topsoil (model I).

sealing is considered as a rainfall energy dependent decrease of the saturated conductivity of the crust. To investigate the effect of different sealing conditions on runoff, simulation studies assuming various hydraulic conductivities of the crust were carried out for a loess soil under sugar beet for periods from April to June with a precipitation resolution of 5 minutes. During this time, soil is bare or sparsely covered and rainfall with high intensities occurs. Calculations were terminated at the end of June because the increasing soil cover of the sugar beet reduces the impact energy of rainfall. The predicted cumulative runoff from April to June in relation to the cumulative rainfall is shown in Fig. 2 for various assumed conductivities in the topsoil (average for conductivity of surface crust + plough layer). Each point on a specific curve represents the result for a specific year. Thus, in dry years (50 mm rainfall), no runoff is to be expected when the topsoil has a saturated hydraulic conductivity less than 10 cm d^{-1}. In wetter years (150 mm or 250 mm of rainfall during April - June) even for high conductivities, considerable amounts of runoff can be expected to occur.

Data analysis of the daily rainfall intensity in comparison with runoff occurance indicates that especially rainfall events with > 2 mm/5 min can be expected to initiate greater amounts of runoff. On the basis of climate data from Hannover, it can be concluded that high rainfall intensities occur mainly in May and June. For the time period analysed, on the average 18 events with high intensities occured in June in southern Lower Saxony with a mean duration of 8.6 minutes. Therefore, one of the main ways to prevent runoff is maintaining a high degree of soil cover with plants or mulch early in springtime (see companion paper of Roth & Helming in this volume).

One aspect the model cannot account for is runoff generated in wheel tracks. Tab. 1 shows results of runoff measurements carried out during the growth period of sugar beets on the loess slope in Adenstedt for the years 1990 and 1991 (no measurements on wheel tracks were carried out in the years before). In both cases, runoff between wheel tracks was negligible because of the low total amounts of rainfall in those years, even though there were visible signs of surface sealing (Bohl & Roth, 1993). In contrast, runoff from the wheel tracks was quite considerable in 1990. This was due to the very low saturated conductivity measured in the wheel tracks (0.5 cm d^{-1}), so that even rainfall of small intensity was able to generate runoff. No appreciable runoff was observed in 1991 owing to the relative dryness of that year.

Table 1: Runoff measured during the growth period of sugar beets on a 200 m long loess slope for a segment between wheel tracks (2 m width) and for the wheel tracks only (0.4 m wide).

Period	Rainfall (mm)	Runoff between wheel tracks (mm)	(% of rain)	Runoff from wheel tracks (mm)	(% of rain)
1990					
30.3 - 26.4	53.2	0.1	0.2	12.0	22.6
27.4 - 11.5	18.0	0.1	0.6	12.4	68.9
12.5 - 7.6	21.2	0.0	0.0	0.0	0.0
8.6 - 7.7	51.8	0.1	0.2	3.4	6.7
8.7 - 23.7	11.2	0.0	0.0	0.0	0.0
24.7 - 2.9	107.8	0.2	0.2	5.0	4.6
1991					
10.4 - 9.5	12.8	0.0	0.0	0.0	0.0
10.5 - 21.5	18.5	0.0	0.0	0.3	1.6
22.5 - 19.6	17.4	0.0	0.0	0.0	0.0
20.6 - 21.6	8.5	0.0	0.0	0.3	3.5
22.6 - 30.6	56.0	0.0	0.0	3.3	5.9
1.7 - 26.7	48.5	0.0	0.0	0.4	0.8

Depending on the compactness of the wheel tracks as a function of axle load and soil moisture at the time of wheel passing, and also depending upon the frequency of wheel tracks present on a field, runoff can occur in amounts great enough to affect the water balance of a field. Moreover, these results indicate the potential risk that wheel tracks represent for the initiation of rill or gully erosion. This aspect requires further study, not only to quantify the wheel track effect on a yearly basis, but also to study the means a farmer has to manage detrimental effects of wheel tracks.

Besides runoff, lateral flow may also play a role in hydrological processes in regions with slopes. Evidently lateral flow must be expected whenever soil layers with low hydraulic conductivities occur below rooted soil horizons. Further simulation studies were carried out to study the relation between drainage and lateral flow by varying K_{sat} of an imaginary stagnic horizon. To study this effect a simple two layer experiment was carried out. Plant uptake was set to zero, and water flow in vertical and horizontal direction was studied as a function of varying K_{sat} values for the stagnic horizon (which could also be a compacted plough layer). Two rainfall periods each of 90 days (climate data for 1971 and 1978) with a time resolution of 5-minutes were used for the simulations with model I. Calculations began with an initial water content at field capacity (Ψ=60hPa). The cumulative interflow rates in percent of the cumulative drainage rates for these simulation periods are presented in Fig. 3.

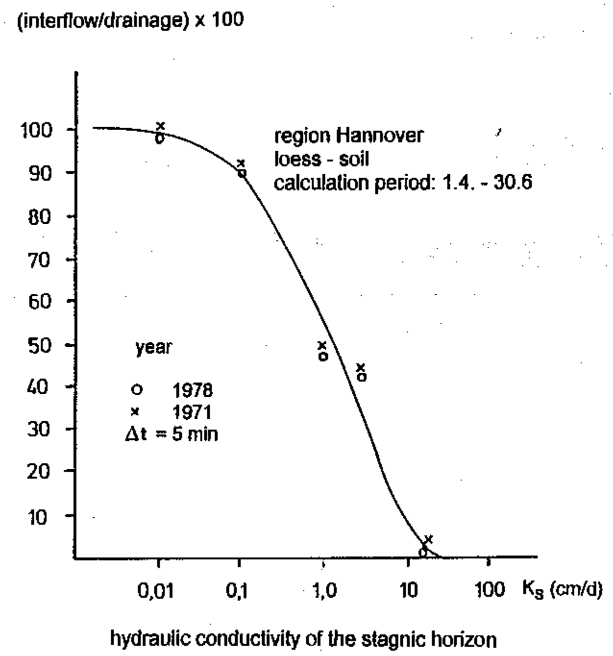

Figure 3: Interflow in percent of drainage for various hydraulic conductivities of an imaginary stagnic horizon (cumulative results of two 90 day calculation periods with a time resolution of 5 minutes, model I).

As shown in Fig. 3, apparently interflow becomes important under the climatical conditions of northern Germany whenever the saturated hydraulic conductivity of the stagnic horizon or the compacted layer is less than 10 cm d^{-1}. Such values can often be encountered in compacted layers, meaning that soil compaction is not only a problem with respect to root penetration, but also in terms of enhanced lateral movement of water, and in consequence, of nitrate or pesticides.

CONCLUSIONS

Results of the case studies presented here indicate that factors related to relief can greatly influence the water regime of hilly agroecosystems. Relief affects climatic conditions mainly in terms of net radiation energy, which influences evapotranspiration, soil moisture in the top soil and infiltration. On soils with weak structure or exhibiting anthropogenic or pedogenic compaction layers, surface runoff and interflow may occur more frequently. In wetter years or years with higher rainfall intensities during storm events, runoff may play an equally important role in runoff generation as wheel tracks, but generally it appears that wheel tracks will invariably lead to runoff at some time during the growth period.

From the simulation studies presented, it can also be concluded that runoff and interflow will not play an important role unless saturated conductivities of surface seals or wheel tracks are well below the mean rainfall intensities, and rainfall amounts remain small during the crucial period from sowing to total soil cover by the crop canopy. In the first case, covering the soil with mulch offers an effective means of avoiding surface seal induced runoff. In the second case, using light tractors with fertilizer and spraying implements having a wider working span will reduce the frequency and compactness of wheel tracks after sowing.

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INFILTRATION RATES AND EARTHWORM POPULATIONS UNDER NO-TILL AND CONVENTIONAL TILLAGE IN INDIANA, USA

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ABSTRACT

Earthworms can play an important role in maintaining and improving soil physical properties and soil quality, especially under reduced tillage systems. Several studies were conducted on farmers' fields during 1992 and 1993, to better determine the response of earthworm populations to tillage systems as practiced by farmers, and the potential changes in infiltration rates as affected by earthworms. Earthworm populations were determined on fourteen paired no-till/conventional tillage fields located on a variety of soils throughout the state. No-till fields generally had higher populations of both shallow-dwelling and deep-burrowing species than the conventional fields. Ponded infiltration rates were determined on seven of the paired sites. On some of those sites, the differences in infiltration rates under no-till vs. conventional tillage may be attributable to differences in the earthworm populations. During 1993, sprinkling infiltration tests were performed on one farmer's no-till and conventional fields, in areas with or without significant *Lumbricus terrestris* activity. The objective was to determine the magnitude of the impact of *L. terrestris* on infiltration rates, under both types of tillage systems, at four different times during the season.

INTRODUCTION

Earthworms can play an important role in maintaining or improving soil physical conditions such as tilth, aeration and water infiltration. One of the advantages of conservation tillage systems, particularly no-till, is that earthworm populations will often increase compared to conventional tillage systems. Generally, water infiltration rates have been found to increase under no-till compared to conventional tillage, but occasionally they have been found to decrease or stay the same. Our working hypothesis is that the presence or absence of a "significant" earthworm population may be an important determiner of whether infiltration rates increase or decrease in no-till vs. conventional systems.

We have previously measured earthworm populations on a range of tillage systems at two Agricultural Research Centers in Indiana, USA (1,2). In order to more confidently extend these results to a wider variety of soils in Indiana and the U.S. Cornbelt in general, we needed earthworm measurements on long-term no-till fields managed by farmers on a range of soil types. The objectives of the 1992 studies were: 1) to determine earthworm populations under no-till vs. conventional (moldboard or chisel plow) systems on a variety of soils and sites in Indiana and Illinois, 2) to determine the relationship between selected soil properties and earthworm populations, and 3) to test the hypothesis that the ratio of earthworm numbers in no-till vs. conventional was correlated to the ratio of infiltration rates on those same two systems. The objective of the 1993 study was to determine the impact of *Lumbricus terrestris* activity on water infiltration rates under both no-till and disk tillage systems.

METHODS

Earthworm populations

In 1992, fourteen paired sites were located on farmers' fields in Indiana and Illinois. A variety of soil types within the Wisconsin-age glaciated region of these states were represented. Soil series names, texture, and drainage class of each site are listed in Table 1. Each paired site consisted of a no-till and conventional tillage (chisel or moldboard plow) field on the same soil type, located as close together as possible (within 1 km distance of each other). Most of the no-till fields had been managed in no-till for at least 5 years. Fields were in a corn (*Zea mays* L.) - soybean (*Glycine max*) rotation, and counts were made in the spring following a soybean crop.

Earthworm counts and observations were made during April 1992, when earthworms are active and soil moisture conditions favor shallow (0-25cm depth) activity of "shallow-dwelling" (endogeic) species. At each field, 12 soil samples (45 x 10 x 25 cm deep) were taken with a specially designed metal sampler (similar to one described by Zicsi (3)) and were then hand-sorted for earthworms. Total soil area sampled was therefore 0.54 m^2 per field. This sampling procedure is suitable for shallow-dwelling earthworm species but does not quantitatively recover deep-burrowing species ("nightcrawlers," or *Lumbricus terrestris*). Nightcrawler activity was estimated by observing the presence or absence of middens in the field. A subsample of the adult earthworms recovered during sorting were identified to genus (*Octolasion*) or species either in the field or back in the lab within two days of sampling.

Ponded infiltration-1992

Seven of the fourteen paired sites described above were chosen for ponded infiltration measurements (4). Water was ponded to a depth of 7.5 cm in a 1.5 x 1.5 m area for a total of three hours. Steady-state infiltration rates of no-till vs. conventional were compared.

Sprinkling infiltration-1993

A no-till field and a conventional (disk) tillage field were chosen, both of which had areas of the field with *L. terrestris* activity and other areas of the field without such activity. Infiltration was measured using a portable sprinkling infiltrometer that delivered 7 cm water/hr to a 1.2 x 1.2 m area. Infiltration was measured four times during the growing season: 1) before any spring fieldwork began, 2) immediately after planting, 3) three weeks after planting, and 4) after harvest.

RESULTS AND DISCUSSION

Earthworm populations

Shallow-dwelling earthworm species populations ranged from 2 to 343 earthworms per m^2 at the time of sampling (Table 1). Of the 14 paired sites, 8 sites had more worms in no-till than conventional, 4 sites had roughly equal populations in both systems, and 2 sites had slightly lower populations in no-till than conventional. A paired t-test confirmed a significant difference in populations with tillage system. The results confirmed previous research findings that no-till generally leads to increased earthworm populations.

Significant *L. terrestris* midden activity was noted on 9 no-till and 3 conventional sites (Table 1). On some fields almost every piece of crop residue that was present on the soil surface had been pulled into middens by *L. terrestris*. This observation suggests that percent residue cover alone may not be adequate to determine compliance with erosion control standards (high infiltration, less runoff, less erosion), once sufficient time has elapsed for *L. terrestris* populations to build up.

Within the no-till fields there was a weak correlation between earthworm (shallow-dwellers) counts and clay content, but the textural range was too limited to make any generalizations. The two sandy loam soils had relatively low populations, as had been expected, but several of the silt loams were also low. The two dominant species over all sites were *Apporectodea tuberculata* and *A. trapezoides*. *Lumbricus rubellus* was found at a few sites and predominately in the no-till fields. It was the most prevalent species in the Crosby no-till fields of sites 5 and 12. A species of *Octolasion* comprised almost half the population at the Pewamo no-till field of site 11, and several other sites had a few individuals. *A rosea* was present in small numbers in all three no-till fields in Illinois (sites 15-1,2,3).

The population differences among locations are most certainly due to a complex mix of factors including soil type, tillage and crop history, chemical (insecticide) history, number of years in no-till, climate and weather, etc. A more detailed field history may be able to explain some of the differences.

Ponded infiltration-1992

On five of the seven paired sites, the data were consistent with the hypothesis that the relative ratio of earthworm numbers in no-till vs. conventional was correlated to the relative ratio of infiltration rates on those systems. Sites 5 and 15(1) both had much higher populations of shallow-dwelling worms in no-till than conventional, and also had *L. terrestris* present in no-till but not conventional (Table 1). Steady state infiltration rates were 3.8 and 2.6 times higher in no-till than conventional for sites 5 and 15(1), respectively.

Sites 11 and 13, however, had large increases in earthworm numbers, including *L. terrestris*, under no-till compared to conventional, but did not exhibit differences in infiltration rate. Reasons for the similar infiltration rates are not clear, but one possibility is that the earthworm population increase was relatively recent and there had not been sufficient time to impact infiltration yet. Another factor that may contribute is that earthworm observations were made in April, while the worms were most active, but the infiltration rate was measured in late June-July on those sites. Infiltration measurements at several times during the season were made in 1993.

Sprinkling infiltration-1993
Before spring field work began, the conventional tillage without middens had the highest infiltration rate and conventional tillage with middens had the lowest rate, possibly due to crusting of the bare soil between middens. Immediately after planting (time 2) and three weeks after planting (time 3), no-till with middens had the highest infiltration rates while conventional with middens still had the lowest rate. In general *L. terrestris* activity, as evidenced by middens, increased infiltration rates within no-till systems. However the middens within conventional systems appear to not be persistent enough to affect infiltration, and therefore residue cover itself may be a more important factor for maintaining high infiltration rates.

CONCLUSION

Earthworm populations generally increased under no-till management compared to conventional tillage. Increased earthworm populations, especially the deep-burrowing *L. terrestris*, often but not always leads to increased infiltration rates. More work is needed to understand the different impacts of soil biota on a variety of soils.

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Table 1 Soil description, total number of shallow-dwelling earthworms, and evidence of *L. terrestris* ("nightcrawler") activity under fourteen no-till and conventional tillage sites.

Site #	Soil series	Classification	Texture[1]	Natl. Drn.[2]	Shallow-dwelling Earthworms/m2		*L. terrestris* middens present?	
					No-till	Conv.	No-till	Conv.
5	Crosby	Aeric Ochraqualf	SiL	SPD	159	63	yes	no
6	Fincastle	Aeric Ochraqualf	SiL	SPD	58	29	yes	yes
7	Owosso	Typic Hapludalf	SL	WD	41	39	no	no
8	Martinsville	Typic Hapludalf	SiL	WD	2	16	no	no
9	Ockley	Typic Hapludalf	SiL	WD	39	70	yes	yes
10(1)	Darroch	Aquic Argiudoll	L	SPD	24	26	no	no
10(2)	Onargo	Typic Argiudoll	SL	MWD	24	50	yes	yes
11	Pewamo	Typic Argiudoll	SiCL	PD	168	107	yes	no
12	Crosby	Aeric Ochraqualf	SiL	SPD	296	115	no	no
13	Treaty	Typic Argiaquoll	SiCL	PD	343	35	yes	no
15(1)	Saybrook	Typic Argiudoll	SiL	SPD	259	119	yes	no
15(2)	Saybrook	Typic Argiudoll	SiL	SPD	324	19	yes	no
15(3)	Drummer	Typic Argiaquoll	SiCL	PD	109	16	yes	no
20	Flood-plain		SiCL		237	196	no	no

[1]L - Loam
SL - Sandy loam
SiL - Silt loam
SiCL - Silty clay loam

[2]PD - Poorly drained
SPD - Somewhat poorly drained
MWD - Moderately well drained
WD - Well drained

MEASUREMENTS OF THE WATER INFILTRATION INTO A TILLED AND UNTILLED SOIL USING A RAINFALL SIMULATOR

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ABSTRACT

The objective of this study was to obtain infomation about the water infiltration in a tilled and untilled sandy clay loam soil from the province of Seville (SW Spain). Measurements of water infiltration were carried out using a portable rainfall simulator. The following tillage methods were applied: disc ploughing (DP), mouldboard ploughing (MP), cultivator application (chisel, (CH)) and disc harrowing (DH). A no-tillage (NT) treatment was also considered. The infiltration was measured at two initial soil water contents, 0.20-0.22 cm^3 cm^{-3} and field capacity (0.28 cm^3 cm^{-3}). Infiltration rates were always lower in the NT treatment than in tillage treatments. When the initial soil water content was 0.20-0.22 cm^3 cm^{-3} the pattern of reduction of infiltration rate with time was different in each treatment probably due to a different sealing process of the soil surface. After 30 min. rainfall simulation, infiltration rates of tillage treatments were significantly different (p=0.05) from that of NT, but no significant differences in infiltration rates were observed between tillage treatments. The reduction of infiltration rates with the soil at field capacity showed similar patterns for all tillage treatments. After 30 min. rainfall simulation the infitration rate was significantly different between some of the tillage treatments and from the NT.

INTRODUCTION

In rainfed agriculture soil water profile recharge takes place during the rainfall periods. Water infiltration into the soil is affected by soil surface conditions created by the different tillage methods used. In soils of the Andalusian plain (SW Spain), climatological conditions, characterized by the concentration of rainfall in the autumn-winter period, lead to replenishment of the water storage capacity at the end of winter and sometimes early in the spring.

Some work has been carried out in the last few years to determine the most appropriate tillage methods to achieve optimum replenishment and water conservation in the profile of soils of western Andalusia, for the development of dry farming crops (particularly cereals). The above-mentioned relationships are clearly shown for soils of different textures found in the region (1; 2 and 3).

Characterization of the water infiltration into the soil is very useful for knowing the patterns of the soil profile recharge under different tillage practices and climatic conditions.

Measurements of water infiltration into the soil are carried out by different methods. The double ring infiltrometer (4), the auger hole method (5) and the rainfall simulator (6) among others are widely used. The use of the rainfall simulator is probably more convenient for obtaining results about water infiltration into the soil that more closely represent the process occuring under natural rainfall.

The objective of the present work was to study the water infiltration into a sandy clay loam soil under different tillage and no-tillage treatments using a portable rainfall simulator.

MATERIALS AND METHODS

Field experiments were carried out on a 1 ha plot within the experimental area of the University School of Agricultural Technical Engineering of Seville (Spain), 3 km east of the city of Seville. The plot was subdivided into 3x28 m subplots, with 0.5 m side borders (total width 4 m). The soil of the plot is classified as a sandy clay loam (Haploxeralf) and its general physical properties were given in a previous paper (3).

The following tillage treatments were used: disc ploughing, DP, (30-33 cm depth), mouldboard ploughing, MP, (25-30 cm depth), cultivator application(chisel), CH (18-22 cm depth), disc harrowing, DH, (12-15 cm depth) and no-tillage, NT. Tillage operations were applied during the autumn of 1986. The previous crop was wheat, harvested in June. All tillage and no-tillage treatments were planted with sunflower, in the middle March 1987 with 75 cm between rows and 20 cm between plants in the same row. Three replicates per treatment in random blocks were used. In all plots weeds were controlled by applying glypbosate (4 l ha^{-1}).

Measurements of water infiltration were carried out in the interrow space, one month after planting when the surface covered by the crop was less than 10%. The portable rainfall simulator (Fig. 1), used in these experiments, was developed by the authors (7), and in some aspects is similar to those described by other authors (6 and 8). Briefly, the rainfall simulator consists of three parts, as is shown in Fig. 1:

i) A cylindrical rigid plastic reservoir (A) (5 l capacity) with a built-in pressure regulator (B), based on the Mariotte bottle principle. At the bottom of this reservoir is located a drop-forming system (C) consisting of 20 emitters similar to those used in drip irrigation (type: long path, spiral grooved). The diameter of drops is 4 mm. ii) A cylindrical support for the reservoir (D), that can vary from 1.2 to 1.5 m height using the adjustable part of the support (E). The support also functions as a wind shield in the field. iii) The device for laterally delimiting the soil is a steel cylinder (F), (i.d. 16 cm). Attached to the cylinder is a gutter (G) for the removal of the runoff to a sample bottle (H).

The surface area affected by the simulated rainfall was 201 cm^2. The infiltration was determined by difference between rainfall and runoff at different time intervals. The infiltration rate was measured for two different initial soil water contents: 0.20-0.22 $cm^3\ cm^{-3}$ and field capacity, using rain intensities of 165 and 78 mm h^{-1} respectively. Several site in each treatment were wetted to bring the soil to field capacity These measurements form part of a wider study being carried out since 1984.

Water infiltration was measured with three replications per treatment. A common analysis of the variance was used to compare the mean values between treatments.

RESULTS AND DISCUSSION

Infiltration rates measured at an initial soil water content of 0.20-0.22 $cm^3\ cm^{-3}$ and a rain intensity of 165 mm h^{-1} are shown in Fig. 2a. They clearly show important differences between tillage treatments and the no-tillage treatment. For the NT treatment a practically constant infiltration rate was reached after 15 min. rainfall simulation. In contrast, for the tillage treatments this constant rate was reached at different times in each treatment; after 20 min. in CH and after 25 min. in both MP and DH. In the case of the DP treatment the constant rate seems to be not reached during the time of rainfall simulation used. The different patterns of reduction of the soil's infiltration rate are probably due to differences in the sealing of the soil surface created by the impact of the raindrops, as described, for instance, in (9).

The infiltration rates measured at 30 min. after rainfall simulation (Table 1) were not significantly different ($p=0.05$) between tillage treatments. In contrast, they were significantly different ($p=0.05$) from that of the NT treatment.

The differences found in the time to reach a constant infiltration rate may be due to the different tillage depths in the treatments used, indicating the control of the infiltration rate by the existence of soil layers at different depths of higher bulk density than in the tillage layers. To support this fact, the depth reached by the wetting front was estimated, for each treatment, from the cumulative infiltration (Table 2) and taking into account the mean value of the soil water content at saturation (0.45 $cm^3\ cm^{-3}$). The estimated depths reached by the wetting front are given in Table 3 for all treatments. They clearly show that in all tillage treatments the wetting front was situated below the tillage depth, except for the DP treatment.

The lower values of infiltration rates, found in the NT treatment, than those in the tillage treatments must be related to a more compact soil surface layer in the former than in the others. This is in agreement with the higher bulk density values in the NT treatment than in the tillage treatments found by the authors (3) in the same plots. Higher values of infiltration rates have been found for no-tillage than for tillage treatments by other authors (10 and 11), when the no-tillage soil was mulched. In our case the no-tillage treatment bad a low mulch cover as is typical under our climatic conditions.

Measurements of water infiltration were also carried out with the soil water content at field capacity, using a rain intensity of 78 mm h^{-1}. Results of this experiment are shown in Fig. 2b. These results sbow that a practically constant infiltration rate was reached in all treatments after 15 min. rainfall simulation. The infiltration rate values after 30 min. are shown in Table 1. In general, these values were significantly different ($p=0.05$), except in the case of CH in which the infiltration rate was not significantly different from those of the DP and MP treatments. A short time is neede from the beginning of infiltration to reach saturation conditions in the upper layer when the soil is at field capacity, and thus infiltration is controlled by the saturated hydraulic conductivity (Ks). Differences of Ks between treatments are due to a different total porosity and different pore size distribution created by the different tillage methods used. The estimated depths reached by the wetting front in each treatment (Table 3) show that in all treatments this was situated above the tillage depth, except in the DH treatment in which it just reached the tillage depth.

When the soil was at field capacity the differences between the infiltration rate of tillage treatmeuts and no-tillage treatment were smaller than in the previous case (initial soil water content: 0.20-0.22 $cm^3\ cm^{-3}$).

In Table 4 are shown results of infiltration rates after 30 min. of rainfall simulation (soil at field capacity) and the saturated hydraulic conductivity (Ks) measured in the laboratory for the tillage and no-tillage treatments. In general, the Ks value and infiltration rate are very similar for each treatment. Some discrepancies were observed in the DP and DH treatments (lower infiltration rate than Ks) that may be due to a more effective sealing of the soil surface in these treatments than in the others.

CONCLUSIONS

From the results shown it can be deduced that the reduction of infiltration rate, measured with a rainfall simulator, follows different patterns in the different tillage and no-tillage treatments used whe the initial soil water content was 0.20-0.22 $cm^3\ cm^{-3}$. This may be due to a different sealing of the soil surface as a consequence of the raindrop impact. This reflects a different destruction of the soil structure created by the tillage and no-tillage treatments. After 30 min of rainfall simulation the infiltration rates of tillage treatments were not significantly different.

Wheu the soil was at field capacity the reduction of infiltration rate follows a similar pattern in all treatments. After 30 min of rainfall simulation infiltration rates of some of the tillage treatments were significantly different.

The no-tillage treatment always showed the lowest infiltration rate due to a more compact soil surface layer than in the tillage treatments.

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Table 1 Infiltration rate (i) in the different tillage and no-tillage treatments after 30 min of rainfall simulation. θi: initial soil water content. FC: field capacity.

θi ($cm^3\ cm^{-3}$)	Rain intensity ($mm\ h^{-1}$)	Treatment (i, mmh^{-1}) DP	MP	CH	DH	NT
0.20 - 0.22	165	97.0 a	101.0 a	102.0 a	96.0 a	22.0 b
0.28 (FC)	78	58.5 a	44.4 b	49.2 ab	33.2 c	10.8 d

Values per lines followed by the same letter are not significantly different at the p=0.05 level.

Table 2 Cumulative infiltration (I) after 30 min of rainfall simulation. θi: initial soil water content. FC: field capacity.

θi ($cm^3\ cm^{-3}$)	Rain intensity ($mm\ h^{-1}$)	Treatment (I, mm) DP	MP	CH	DH	NT
0.20 - 0.22	165	71.1	63.5	61.6	57.5	20.4
0.28 (FC)	78	33.3	28.3	29.3	23.8	13.4

Table 3 Estimated depths reached by the wetting front after 30 min of rainfall simulation. θi: initial soil water content. FC: field capacity.

θi ($cm^3\ cm^{-3}$)	Rain intensity ($mm\ h^{-1}$)	Treatment (depth, cm) DP	MP	CH	DH	NT
0.20 - 0.22	165	29.6	26.4	25.6	23.7	8.3
0.28 (FC)	78	19.5	16.6	17.2	14.0	7.9

Table 4 Infiltration rate (i) after 30 min rainfall simulation with soil at field capacity and saturated hydraulic conductivity (Ks) measured in the laboratory.

i ($mm\ h^{-1}$)	58.5	44.4	49.2	33.2	10.8
Ks ($mm\ h^{-1}$)	91.6	45.5	43.5	50.4	11.1

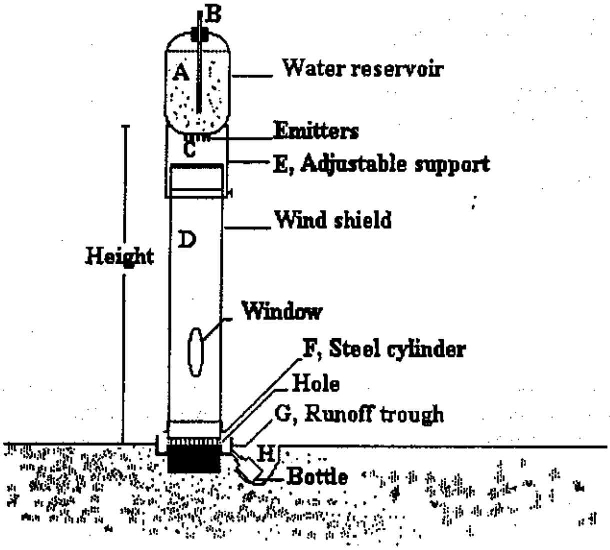

Fig. 1 Vertical cross-section of the rainfall simulator.

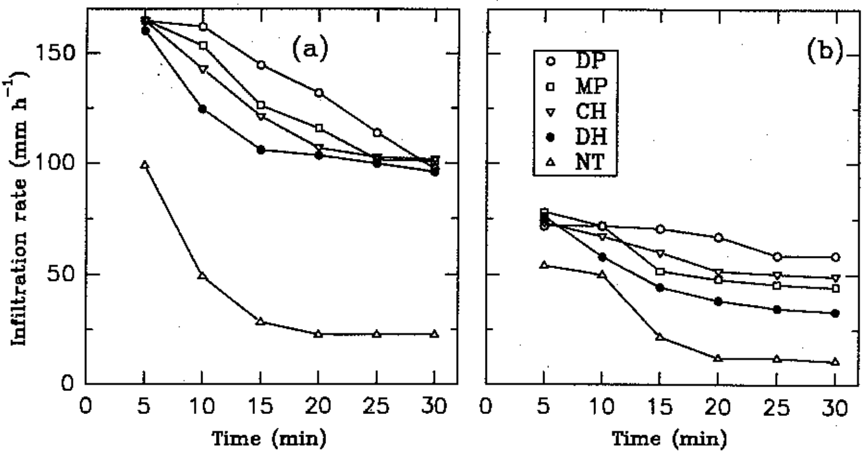

Fig. 2 Infiltration rates measured at different initial soil water contents: (a) 0.20–0.22 $cm^3\ cm^{-3}$ and (b) field capacity.

TILLAGE TO ENHANCE WATER INFILTRATION THROUGH FROZEN SOIL

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ABSTRACT

Soil erosion is serious in dryland farming regions of the northwestern USA. Erosion is a problem on fields with long steep slopes that are seeded to winter wheat. Rain or melting snow on frozen soil causes severe erosion. Infiltration through frozen silt loam soil is almost zero. Field tests were conducted to evaluate the impact of frozen soil tillage on crop production and water infiltration. Infiltration tests were conducted after chiseling and subsoiling when soil was frozen 10 cm deep. Frozen soil infiltration was increased 150% and grain yield not changed when soil was ripped as compared to no-tillage.

INTRODUCTION

In the dryland farming region east of the Cascade Mountains of the Pacific Northwest (PNW) USA (Fig. 1), a unique combination of crop management, climate and topography creates soil water erosion problems. Slopes are steep and long and 70% of the precipitation occurs during the winter when soil is frozen or partially thawed (1,2). Frozen soil layers reduce infiltration and increase the risk of runoff and soil erosion. This risk is especially high in fields with winter wheat (*Triticum aestivum* L.) seedlings, long-steep slopes and limited crop residue cover on the soil surface. Average annual soil losses range from 5 to 50 t/ha but losses in excess of 200 t/ha have been reported (2). These runoff and erosion events associated with frozen soil occur with snowmelt or rain (3).

In this semiarid climate with winter dominant precipitation, winter wheat is grown in rotation with fallow. During the summer-fallow period a dust mulch is created with primary tillage followed by rod weeding to conserve soil water. Deep furrow drills are used to place winter wheat seed through the mulch into moist soil. Although no-tillage summer fallow is ideal for erosion control in dry areas, tillage is necessary to break capillary conductivity which prevents excessive seed zone drying during the fallow year (4).

Crop residue on and near the soil surface is effective in controlling soil erosion (5). "Vertical mulching", a technique that places crop residue in narrow trenches is also effective for runoff and soil erosion control (6). Often there is not sufficient crop residue for erosion control where summer fallow is practiced. Tillage buries crop residue and reduces surface cover. In years when surface cover is insufficient for erosion control, other methods are needed.

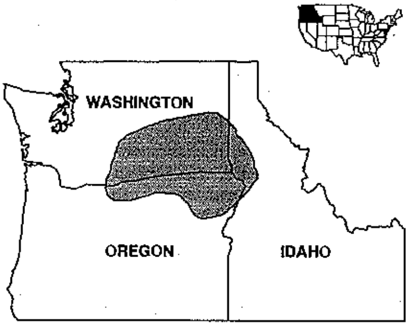

Fig. 1. Dryland farming region east of the Cascade Mountains of the Pacific Northwest (PNW), USA.

Pikul et al. (7) suggested ripping soil as an additional erosion control technique for this region. Ripping frozen soil was found to enhance infiltration and increase erosion control without sacrificing wheat yield (8). The slot produced by ripping provided an infiltration pathway through the frozen soil layer to intercept runoff during rain or melting snow when soil was frozen, and to store this water below the frozen soil layer.

The objective of this research was to evaluate the impact of tilling frozen soil in the dryland farming region of the PNW on wheat yield and water infiltration.

MATERIALS AND METHODS

Six experimental sites in northeast Oregon near Pendleton were established during 1990 to 1993 on fields seeded to winter wheat to evaluate tilling frozen soil for enhanced water infiltration. Experimental sites 1 and 2 in 1990, site 5 in 1991 and site 6 in 1993 were in areas which typically have a wheat-summer fallow rotation and receive from 250 to 350 mm of annual precipitation. The soil for these sites was Walla Walla silt loam (coarse-silty, mixed, mesic Typic Haploxeroll). Sites 3 and 4 in 1991 were areas, where annual precipitation exceeds 400 mm and peas (*Pisum sativum* L.) are grown in rotation with wheat. Site 3 was on a Palouse silt loam (fine-silty, mixed, mesic Pachic Ultic Haploxeroll) and site 4 was on a Waha silty clay loam (fine-loamy, mixed, mesic Pachic Argixeroll). These soils are well drained, and deep (1.5 m or greater to basalt).

Treatments were no tillage and no traffic (NTNT), traffic and no tillage (T), tillage with shank (S), tillage with shank plus rotary subsoiler (SR) and tillage with only rotary subsoiler (R). Experiments had either four or five replications. A tool designed for tilling frozen soil with a minimum of soil disturbance (8) was used for the tillage treatments. In 1992, the winter was warm and treatments were not installed because the soil did not freeze more than 5 cm deep. Winter wheat was seeded in October and tillage done when the soil was frozen about 10 cm deep and wheat was in the seedling stage of development. Tillage depth was 28 cm and on contour.

In 1990 (8) and 1991, 20 or more plants were excavated from treatments NTNT, T and SR at sites 1-4 to assess the impact of frozen soil tillage on root diseases. Plants were excavated adjacent to the tillage slot (less than 5 cm from the center of the slot) in treatment SR and from tracked areas in treatment T. Plants were taken to the laboratory, and rinsed with water to remove soil from root systems. Each plant was evaluated for the percent of seminal roots with Pythium, root rot or take-all, percent of plants with eyespot and severity of Rhizoctonia root rot on seminal and coronal roots. Wheat was winter killed in 1991 at site 5.

Grain yield and heads per unit area were determined for all plots by hand harvesting plants from 1.5 m^2. The harvest area in each plot was a 0.6 by 2.5 m. The 2.5 m dimension was centered over the tillage slot and extended across tracks made by the tractor pulling the tillage tool.

Water infiltration was measured at site 5 after tillage when the soil was frozen. Infiltration was measured in 15 cm wide by 1 m long areas parallel to frozen soil tillage mark. Metal plates 45 cm square were driven into the frozen soil 1 m apart and perpendicular to the direction of tillage. Gaps between the plates and soil were sealed with bentonite. These plates and ridges between wheat rows made by planting equipment defined a 15 cm by 1 m infiltration reservoir. The quantity of 0°C water required to maintain a 2 cm hydraulic head above the soil surface was recorded at 5 min intervals. Measurements were made for one h in three replicates of SR and NTNT treatments .

RESULTS AND DISCUSSION

Tillage treatment S made a narrow slot that remained open during the winter. SR treatment made a narrow slot with pock marks approximately 1 m apart. Pock marks were observed to serve as small reservoirs for intercepted runoff and provided access for surface water to enter channels created by the shank . The rotary subsoiler (R) used alone did not consistently penetrate frozen soil.

Take-all was the only plant disease observed to be consistently influenced by mechanically damaging roots with frozen soil tillage. Table 1 shows the impact of frozen soil tillage in 1990 and 1991 on take-all incidence.

Tilling frozen soil increased the percent of seminal roots with take-all lesions by as much as 9 fold. Take-all infection occurs through root contact with the fungus (9). It is possible that the tillage tool spread the fungus to root systems as the tool passed through the soil. Severe infestations of take-all can reduce wheat yields by as much as 50% (9). The only other observed incidences of wheat diseases that were significantly influenced by frozen soil tillage or traffic were Pythium at site 1 which was higher in the tilled plots than either NTNT or T plots (9, 13 and 20 % of seminal roots infested in NTNT, T and SR plots, respectively) and Rhizoctonia root rot which was slightly higher at site 4 in SR plots as compared to NTNT and T (4.2, 4.2 and 4.5 rating for NTNT, T, and SR, respectively). A rating of 4 = lesions on 1-2 main axes and a rating of 5 = lesions on 3 or more main axes.

Table 1. Effects of frozen soil tillage on incidence of take-all lesions on winter wheat seminal roots.

Soil Disturbance	1990 site 1	1990 site 2	1991 site 3	1991 site 4
	------------------- % of seminal roots with lesions ---------------			
None (NTNT)	1.0	4.5	4.4	1.9
Tracks (T)	2.6	1.4	1.3	1.0
Shank + Rotary (SR)	9.3	14.4	32.8	17.3
LSD 0.05	6.0	6.9	16.8	9.1

Wheat yields were not depressed by frozen soil tillage (Table 2). Only at site 4 were there significant differences where rotary subsoiling (R) increased the yield over the control (NTNT), traffic (T) and ripping with a shank (S). Site 3 was located in the same field and within 400 m of site 4 but there were no significant yield differences at site 4. Heads produced per unit area were not significantly influenced by the five treatments at any of the sites. Disease injuries were not manifested in yield reductions. Most wheat plants can withstand mild infections of take-all without yield reductions (9). These results suggest that frozen soil tillage in the PNW can be done in fields with wheat seedlings without reducing grain yield.

Table 2. Influence of frozen soil tillage on winter wheat yield in the PNW. Not significant at P=0.05: ns.

Soil Disturbance	1990 site 1	1990 site 2	1991 site 3	1991 site 4	1993 site 5	Mean
	------------------------------ kg/ha ---------------------------------					
None (NTNT)	3884	4395	4820	6367	5416	4976
Tracks (T)	4012	4764	5782	6035	5584	5235
Shank (S)	3911	4301	6145	5920	5389	5133
Shank + Rotary (SR)	3958	4684	4659	6697	5336	5067
Rotary (R)	4260	4462	5462	7232	5215	5326
LSD 0.05	ns	ns	ns	966	ns	----

There was more water infiltration into tilled (SR) than non-tilled plots (NTNT) (Fig. 2). After one hour of infiltration the mean accumulated infiltration in the tilled plots was 13 mm, which was 150% higher than the non-tilled plots. Although this rate of infiltration is low, the infiltration rate of these soils is approximately 20 mm/h in an unfrozen state(7).

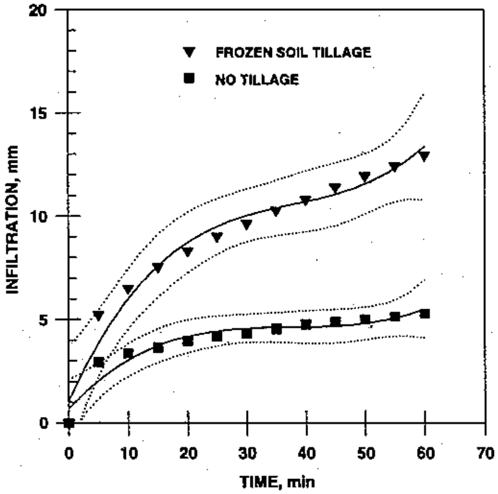

Fig. 2. Cumulative water infiltration for no-tillage and frozen soil tillage for a Walla Walla silt loam in the PNW. Dotted lines indicate 95% confidence intervals.

CONCLUSIONS

Tilling frozen silt loam soil in fields with winter wheat seedlings for soil erosion control in the Pacific Northwest dryland region east of the Cascade mountains would benefit water infiltration during the critical period when there is a layer of frozen soil. This technique would not result in depressed grain yields adjacent to the tilled slot due to disease or stand reduction.

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Seasonal variability in soil moisture due to tillage and residue mulching of a clay soil

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Abstract

Tillage operations are expected to improve the soil macrostructure (cloddiness) and aggregate strength of dispersive soils that have low organic matter content and bulk density. Likewise residue mulching reduces rainwater losses through runoff and evaporation by its mulching effects, dissipation of raindrop energy and reduction of overland flow velocity. These soil surface conditions are favourable to the improvement of infiltration and subsequent conservation of moisture within the soil. The seasonal trends in profile soil moisture under these practices, would show whether the moisture available would sustain crop growth during critical dry spell periods.

In this experiment, seasonal soil moisture variabilities under conventional tillage tied ridging and residue mulching in a clayey soil were investigated over two rainy seasons (short and long rains). The long rains account for approximately 65% of the total annual rainfall. Over the study period of one year, the total seasonal rainfall received in the long and short rains periods were 408 mm and 210 mm respectively. The results obtained showed that crop residue mulching had the highest total soil moisture content followed by conventional tillage and tied ridging. Tied ridging had the least available soil moisture content throughout the two rainy seasons. The tied ridges performed poorly primarily because of an increased surface area resulting in high evaporation water losses (4.9 mm/day) and also due to the lack of surface runoff water to impound and conserve. Therefore under these environmental and soil conditions, crop residue mulching could be recommended as the most appropriate soil management practice.

Introduction

Whereas most of the dominant soils in marginal rainfall areas of Kenya are of high agricultural potential, the major limiting factor to optimum crop production is soil moisture. The low soil moisture conditions in these areas are attributed to low infiltration due to surface sealing and crusting, compaction and low organic matter content, and subsequent high runoff rates. Relatively low, erratic and poorly distributed rainfall in these areas contributes significantly to this soil moisture deficit. The average mean annual rainfall at Kalalu, Laikipia, based on 54 years data is 711 mm.

Where runoff water losses are normally high, changes must be made so that water is conserved in the soil in situ to sustain crop growth (Macartney, 1970). The conservation of soil moisture in marginal rainfall areas requires appropriate tillage practices that not only improve rain penetration and retention, but also conserve adequate soil moisture for good plant growth.

The use of tillage practices for dryland farming should focus on the improvement of physical soil properties to conserve more soil moisture and increase yields. This study therefore attempts to establish the effects of conventional tillage, tied ridging and crop residue mulching on soil moisture conservation under marginal rainfall conditions. These tillage practices are expected to enhance infiltration, conserve soil moisture, reduce surface runoff and subsequently sustain crop growth during the dry periods.

Materials and methods

The soils at the Kalalu experimental site are well drained deep clay soils and are classified as ferric Acrisols. Three infiltration tests were conducted over a three hour period using a double ring infiltrometer. The soils had an average final infiltration rate of 9 mm/hr after 3 hours. Twenty seven soil samples were randomly taken (up to a maximum depth of 150 cm) from each plot and analyzed for physico - chemical properties of the soil.

A completely randomized block design with three treatments and three replicates was used in this study. Each plot 4m x 10m was enclosed by a metal sheet boundary (depth of 15 cm) with one open end on the downward side of the slope (2%) to allow free flow of runoff water. The plots were separated by 15 cm high sheet metal that prevented any runoff or soil particles from spilling over from one plot to the other. An aluminium access tube of 49 mm diameter (for monitoring soil moisture) was installed at the centre of each plot to a depth of 120 cm.

Maize stover was used on the mulch plots at a rate of 3 tonnes/ha. The mulch was applied evenly on each plot. Tied ridges had a spacing of 40 cm (as per beans row spacing) in the short rains and 75 cm (as per maize row spacing) in the long rains period. The specifications of the tied ridges were: ridge depth - 20 cm, ridge width - 15 cm, tie height - 15 cm and tie interval - 2m. One conventional tillage operation was done before planting. This tillage operation involved loosening of the top soil using forked hand hoes to a depth of 20 cm.

The neutron moisture probe used in this experiment was calibrated at two depth ranges of 0-90 cm and 90-120 cm (see Figure 1). The calibration involved dry and wet runs in two access tubes installed outside the experimental plots. The readings of shield and soil counts together with the corresponding volumetric moisture contents were used to plot the calibration curves. The two calibrations were necessary because of the presence of iron concretions (known to affect count readings) at the lower depth range (90 - 120 cm).

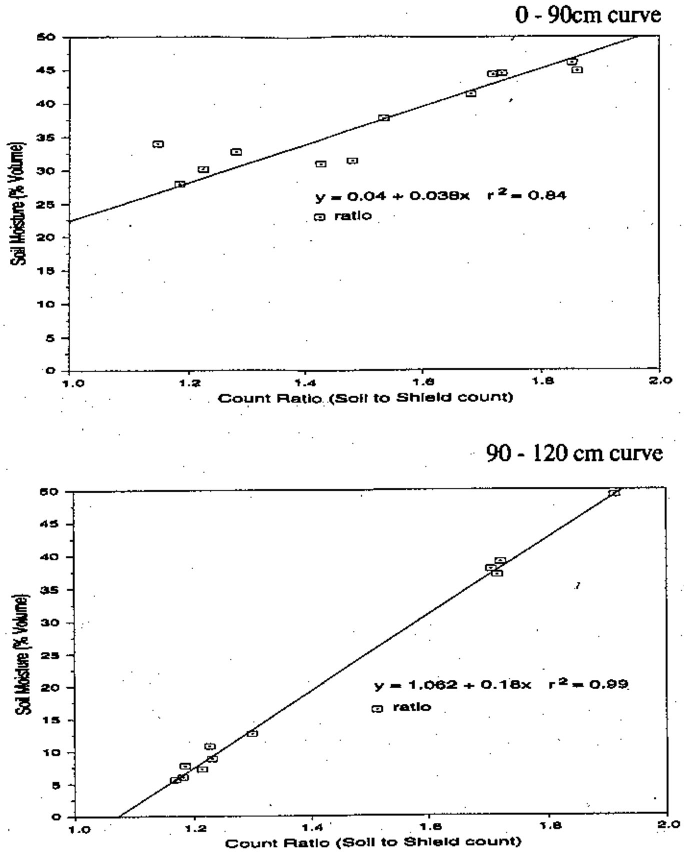

Fig. 1. Calibration curves of neutron probe for the 0 - 90 cm and 90 - 120 cm soil depths.

Results and discussion

Soil Properties

The soils at the experimental site showed an increase in clay down the profile except at the 90-120 cm depth where there was a decrease. At this depth, there were iron concretions. These soils have a moderate organic matter content in the A horizon, and the soil reaction varies from moderately acid to nearly neutral and the soil is adequately supplied with exchangeable bases (see Table 1). Although the soil at the site showed thin cracks during the dry spell, the clay mineralogy results indicated an illite/kaolinite clay mineral assemblage throughout the profile. These minerals occurred in small amounts (Gicheru, 1990).

Table 1

Soil profile characteristics of a ferric Acrisol (Gicheru, 1990)

Soil depth (cm)	Soil pH	Bulk density (kg/m^3)	Soil particle distribution			Soil texture	Organic matter (%)	Field capacity (% V)	Wilting point (% V)	Available moisture (% V)
			Sand (%)	Silt (%)	Clay (%)					
0 - 30	1.2	1300	21	23	56	C	2.0	43.6	35.7	7.9
30 - 60	6.5	1200	18	16	66	C	1.7	45.2	27.9	17.3
60 - 90	5.6	1300	16	14	70	C	0.7	39.2	31.2	7.9
90 - 120	5.5	1400	22	18	60	C	0.7	36.1	32.1	4.0

Bulk density of this soil ranged from 1400kg/m^3 in the 90-120 cm to 1200kg/m^3 in the 30-60 cm soil depth. The high bulk density in the lower horizon (90-120 cm) could be due to the iron concretions found in this horizon. These soils showed a high initial infiltration rate and a final infiltration rate of 9 mm per hour.

Profile soil moisture

Table 1 shows the soil moisture content at field capacity and wilting point. Field capacity of this soil which is predominantly clay ranged from 45.2 to 36.1 percent by volume and wilting point ranged from 35.7 to 28.9 percent by volume and hence the available soil moisture for plant growth which was retained between field capacity and wilting point ranged from 16.3 to 4 percent by volume. The field capacity and the wilting point were determined in the field and therefore there was a probability of an error since the conditions were not controlled and hence the greater range of moisture content between the wilting point at a depth of 0-30 cm and 30-60 cm (28-36%). The total available soil moisture in the profile was 36.1 percent by volume.

Seasonal soil moisture

Short Rains Period, 1988/89

There was no runoff observed during the short rains crop growing season (November, 1988 to February, 1989). For the four months rainy season, the total amount of rainfall and the average daily potential evaporation rate were 210 mm and 4.3 mm/day respectively. Cumulative soil moisture content for beans was highest in the conventional tillage and lowest in the tied ridges (see Table 2).

The values of cumulative soil moisture content presented in Table 2 are the averages of the total profile moisture for the respective crop growth periods. This moisture content represents what was available to the plants.

Table 2

Cumulative soil moisture for beans, short rains period, 1988 (Gicheru, 1990)

	Cumulative soil moisture content (% volume)		
Crop Stage	Residue mulch	Conventional tillage	Tied ridging
Emergence	27.6	30.6	27.4
Budding	25.6	25.6	25.6
Flowering	21.3	21.2	15.3
Maturity	10.0	13.9	6.0
Harvesting	5.5	8.9	0.7

During this period, all the treatments showed some moisture deficit at a depth of 30 cm from January upto early March when the crop was being harvested. At depths of 60 cm and 90 cm, all the treatments had available moisture with tied ridges having the least. At the 120 cm depth, mulched and conventionally tilled plots had available soil moisture throughout the crop growing period. Tied ridges had no available soil moisture at this depth throughout the short rains period. Overall, the total soil moisture content for all treatments were not significantly different at P(0.05) level. Tied ridge plots were drier on average than the other treatments and hence exhibited some moisture deficit.

Seasonal soil moisture distribution down the profile varied with treatments (see Figure 2). During the 1st week after planting, the conventionally tilled, residue mulch and tied ridge plots had 4.1%, 3.8% and 3.8% of available moisture respectively at 0-30 cm depth range. At the harvesting stage (15th week after planting) the conventionally tilled, residue mulch and tied ridged plots had a soil moisture deficit of 7%, 9.4% and 8.3% respectively. The mulched plots generally had more available moisture as depicted by the observed vigorous crop performance and subsequent high plant water uptake. The increase in plant water uptake in later stages of plant growth led to the soil moisture deficit at the harvesting stage. There was a high moisture content observed in intermediate soil layers. This could be attributed to their high clay content and also to the moisture redistribution down the profile.

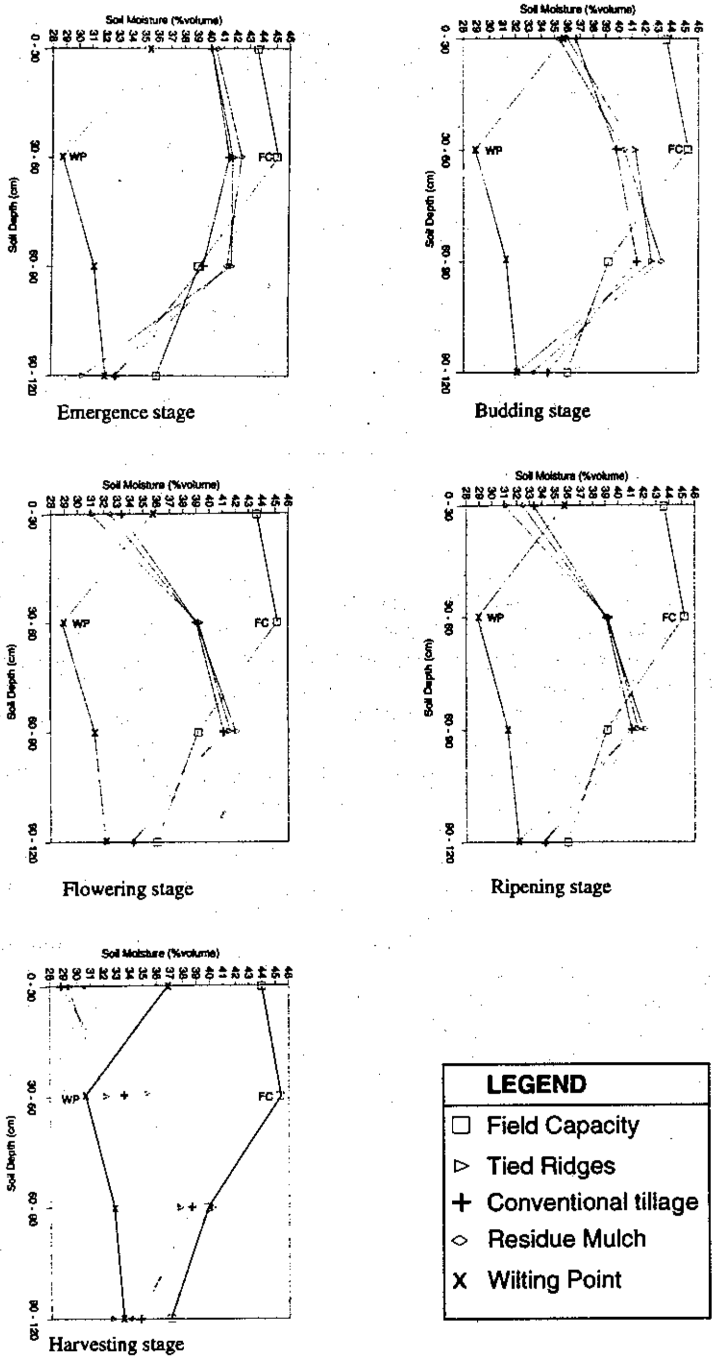

Fig. 2. Soil moisture distribution within the treatment soil profiles at various crop growth stages, short rains season, 1988 (Gicheru, (1990).

Long Rains Period, 1989

During the long rains period (April to July, 1989), there was no runoff observed in any of the plots. The total amount of rainfall and average daily potential evaporation for the three months period were 408 mm and 4.4 mm/day, respectively. Crop residue mulch plots had the highest cumulative soil moisture followed by conventional tillage and tied ridged plots (see Table 3).

Table 3

Cumulative soil moisture for maize, long rains period, 1989 (Gicheru, 1990)

Period after planting (weeks)	Cumulative soil moisture content (% Volume)		
	Residue mulch	Conventional tillage	Tied ridging
3	10.3	14.3	0.2
7	19.6	20.8	4.4
11	147.6	148.8	131.4
14	2.3	6.1	3.8

Cumulative soil moisture content for maize was highest in the conventional tillage and lowest in the tied ridges (see Table 3). Three weeks after planting, there was no available soil moisture in all the treatments at a depth of 0-30 cm. Seven weeks from planting, the tied ridged treatments had the lowest available soil moisture throughout the profile (see Table 3). Conventionally tilled plots had more total available soil moisture throughout the profile and also more available moisture at a depth of 0-30 cm, than residue mulch plots. There was a significant difference at P(0.05) of moisture between the treatments at the 0-30 cm depth. At depths of 30-60 cm and 60-90 cm, the residue mulched plot had the lowest available soil moisture (1% and 5.6% respectively) while conventionally tilled plots had 3.2% and 7.1% and tied ridged plots had the highest 4.7% and 7.2% respectively.

Down the profile, there was available soil moisture at 60 cm and 120 cm depths in all the treatments (see Figure 3). The availability of moisture in these depths could have been contributed by the antecedent moisture from the previous season and also by redistribution of infiltrated water from the long rains. There was a moisture carry over in both conventional tillage and residue mulch treatments but there was none in tied ridge plots.

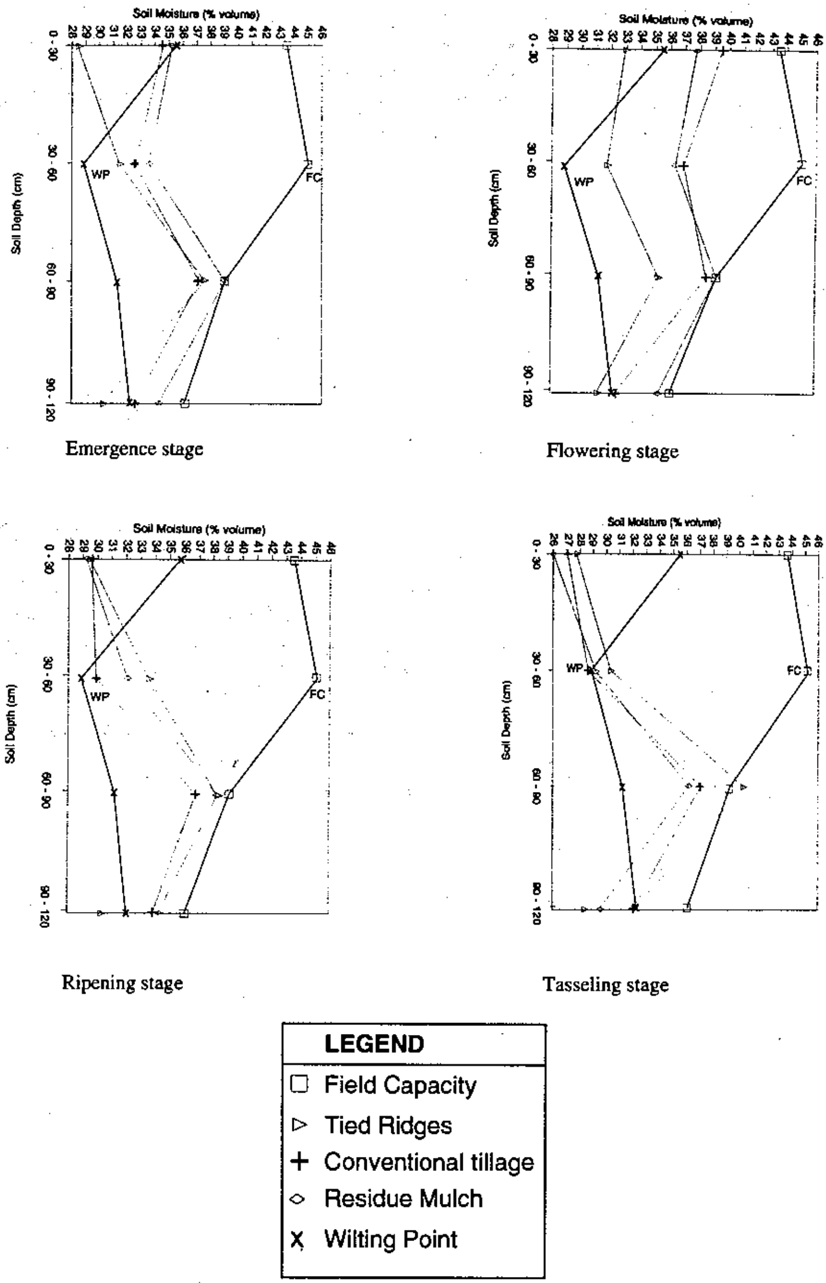

Fig. 3. Soil moisture distribution within the treatment soil profiles at various crop growth stages, long rains season, 1989 (Gicheru, (1990).

Overall during this period, conventionally tilled, residue mulch and tied ridge plots had a total available moisture of 14.3%, 10.3% and 0.2% in the whole profile respectively. Table 3 shows that the tied ridge plots had the lowest cumulative soil moisture in the profile and it had the highest soil moisture deficit at the top soil layer (0-30 cm). The tied ridges had a greater surface area exposed than the other treatments and hence could have lost more moisture through evaporation than the other treatments.

Conclusions

The results obtained from this study have established that residue mulching is the most effective soil management practice for conserving soil moisture and subsequently improving crop performance and yield in Kalalu, Laikipia, Kenya. The good performance of the test crops in the residue mulch plots did contribute to the trend in lower cumulative available soil moisture content observed in this treatment during the short and long rains periods. Conventional tillage plots performed better than tied ridge plots because of the soil clods left on the soil surface. These clods dissipated the kinetic energy of the falling raindrops and hence increased the rate of infiltration of rainwater into the soil. Tied ridges were ineffective because there was no runoff water to impound in the test year. Experiences elsewhere (Macartney, 1970; Njihia, 1979; Alem, 1986 and Hulugalle, 1988) have shown that tied ridges perform better than conventional tillage where runoff is harnessed and ponded in the basin. This ponding increases the opportunity time for runoff to infiltrate and hence increases the amount of available soil moisture to sustain crop growth.

Although there were no significant differences in soil moisture between the treatments except within the top soil depth of 0 - 30 cm at emergence and harvesting stages, there were significant differences in cumulative available profile moisture within the two crop growing seasons.

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GROWTH-EFFECTIVE RAINFALL IN MAIZE PRODUCTION UNDER DIFFERENT TILLAGE SYSTEMS IN SEMI-ARID CONDITIONS AND SHALLOW GRANITIC SANDS OF SOUTHERN ZIMBABWE

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ABSTRACT

Crop production in semi-arid areas of Zimbabwe undergoes extreme yield variations. From 1988 to 1993 maize yields ranged from 0 to 7.4 t/ha. Erratic rainfall coupled with limited soil water storage capacity and rooting volume of the shallow sandy soils offers few management options to improve plant water supply. In this study, two conservation tillage systems (mulch ripping and tied ridging) were evaluated and compared to conventional tillage. The objective was to quantify water balance parameters of the different tillage systems.

Based on soil profile moisture determinations and measurements of surface run-off during five years, drainage and growth-effective rainfall were calculated for each season. Growth-effective rainfall was related to the yields obtained and water use efficiency ratios were determined.

Results indicate that both conservation tillage systems increase infiltration compared to conventional tillage. The increased water input into the soil results in higher drainage losses, in particular under the mulch ripping treatment. Growth-effective rainfall was generally highest under tied ridging. High soil evaporation under ridges, however, reduced the water use efficiency of this system.

From a water balance point of view mulch ripping appeared to be the most favourable tillage option for semi-arid areas. Its constraints in a farming system where residue grazing is important are obvious. Therefore, tied ridging with its reduction of run-off and associated low soil loss appeared as the most applicable sustainable tillage option as long as residue grazing is a general practice. Soil management in southern Zimbabwe should generally opt for improving soil cover and rooting volume.

INTRODUCTION

The major constraint in agricultural production in the semi-arid and arid regions of Zimbabwe is the availability of water. As rainfall in these areas is erratic and often of high intensity, conservation tillage systems which capture and store water for maximum use by crops offer crucial advantages. Systems that increase infiltration may also increase drainage if the water-holding capacity of the soils is low. Therefore, it is important to understand the percentage of water effective for plant growth, as drainage losses, especially from conservation systems, may well exceed run-off losses. In dryland farming on well drained sandy soils, crop water supply depends solely on the water stored in the root zone between field capacity and wilting point (1). The main water loss within the soil is drainage beyond root zone.

In Zimbabwe several conservation tillage systems have been tested for their protection and production merits since 1988 (2). In this study two conservation tillage systems, mulch ripping and tied ridging, have been evaluated and compared to the conventional mouldboard ploughing system. Simple methods of calculating water balance parameters, growth-effective rainfall and water use efficiency, under three different tillage systems are applied.

MATERIALS AND METHODS

Experimental site

Experiments were carried out at Makoholi Research Station (1200m a.s.l.). Characteristic for this region is the erratic and unreliable rainfall both between and within seasons (3). Average annual rainfall is between 450 and 650mm (4). The soils are inherently infertile, coarse-grained, granite-derived sands, of the fersiallitic group with about 4-6% clay and 0.5% organic matter (5). The stone line occuring in the 50-80cm depth results in shallow rooting depth (6).

Tillage treatments

Three tillage systems are compared. In the conventional mouldboard ploughing system (CMP) the land was ox-ploughed using a single-furrow mouldboard plough and thereafter harrowed with a spike harrow. In mulch ripping (MR), crop residues from the previous season were left to cover the ground and only rip lines were opened, using a ripper tine. In the no-till tied ridging system (TR)(7), ridges were constructed at 1% slope and spaced at 0.9m and crossties (about two-thirds of the ridge height) built at an interval of 1m in the furrows. All treatments were laid out at 4.5% slope. Tillage operations were done across the slope. Maize (*Zea mays* L.) was grown on all plots at a population of 36000 plants/ha on all treatments.

Water balance parameters

Rainfall (P) and evaporation (E_o) were measured daily using an autographic rain gauge (Casella) and a class A pan respectively. Run-off (R) and maize yield assessments were carried out on 30 x 10m field plots, for MR and CMP treatments, and from 150 x 4.5m for TR treatment. The surface run-off was collected in 15000l conical tanks, installed downslope of the plots. Soil profile moisture content was monitored weekly using a neutron probe (Hydroprobe DR 503).

Root excavations were carried out to determine the maximum rooting depth of maize. Due to the stone line, the deepest roots did not exceed 70cm depth. Field capacity (FC) was determined in situ, where saturated soil was covered with a plastic sheet and allowed to drain for 48 hours. Longer drainage time did not result in differences in the soil moisture. Moisture content at FC was found to be 10.3% by volume, which considering a rooting depth of 70cm, allows a maximum storage capacity of 72mm within the root zone. The wilting point of these soils, determined in situ, was found to be 2.3% by volume (16mm) thus the available water capacity is 8% (56mm).

Drainage (D) was quantified as follows: moisture content before each storm (S_a) was determined by extrapolating values from the soil moisture content curves, as soil moisture was only measured on a weekly basis. Thereafter water input was calculated as rainfall (P) - surface runoff (R). The water input was added to S_a and the amount of water exceeding the maximum storage capacity of the soil (FC) after a storm was considered as drainage. If S_a is the soil moisture content before storm and S_b after storm then,

$$D = S_a + (P-R) - S_b \text{ at FC } (-E_o). \qquad \text{(eq 1)}$$

E_o was only considered for days where rainfall was received for 2 or more consecutive days, by assuming that soil evaporation during rainy days, under saturated conditions, was as high as pan evaporation. During such days, drainage was reduced by evaporation and thus, E_o was subtracted.

Growth-effective rainfall and crop water use efficiency.
Growth-effective rainfall (GER) in this study is defined as the rainfall that contributes to plant growth between planting and physiological maturity. Doorenboos and Pruitt (8) define effective rainfall as rainfall minus surface runoff, deep percolation and evaporation of ineffective light showers which fall on dry soil. Observations during five years have shown that, due to high saturation deficit of the air, light showers below 3mm per storm were non-effective. These storms were therefore not considered. For the calculation of GER the total rainfall (P_i), run-off (R_i) and drainage (D_i) during the actual growing period were used and not the seasonal totals.

$$GER = P_i - R_i - D_i \qquad \text{(eq 2)}$$

Crop water use efficiency (WUE) as defined by Heinonen (9) is "the ratio of marketable yield units per unit of water use". In this study it is a ratio of GER (m^3) and maize grain yield (kg/ha).

RESULTS AND DISCUSSION

Rainfall losses
For all treatments, drainage, run-off, GER and yield varied considerably from year to year as influenced by the amount and distribution of rainfall. The two conservation tillage systems proved to be efficient in reducing water loss through run-off. During the 1992/93 season, for example, total run-off from CMP amounted to 17% of total seasonal rainfall compared to 5% from MR and 3% from TR, (Figure 1). This trend was clear during all five seasons (Table 1). As low run-off results in higher water inputs into the soil, drainage losses were -as expected- higher on conservation tillage treatments. Drainage depends on water input per given storm and on the soil moisture content before storm. Mulch cover protects the soil from high evaporation and helps maintain higher soil moisture contents. Due to higher moisture levels in MR, less water could be absorbed by the soil in the root zone and thus resulted in higher drainage losses.

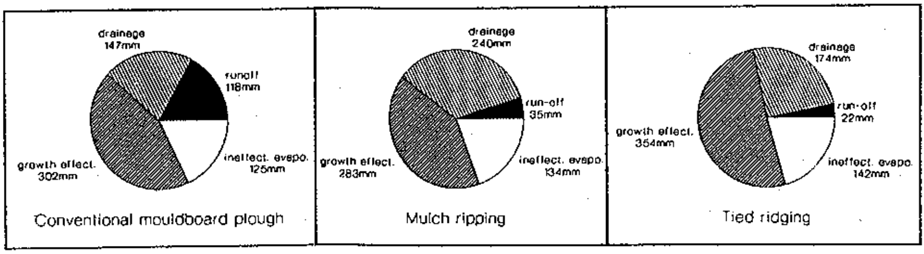

Figure 1: Water balance components from three different tillage systems during the 1992/93 rainy season (total seasonal rainfall = 692mm)

During the 1992/93 growing season, losses of up to 35% of total seasonal rainfall from MR, compared to 21% from CMP and 25% from TR were recorded. Drainage from TR, however, was lower than expected, the reason being that ridging increases surface area and soil temperatures which result in considerably higher soil evaporation and lower soil moisture contents (10). The evapotranspiration (E_T) and GER values comprise therefore a higher percentage of soil evaporation as compared to the same value by CMP and especially by MR where, due to mulch cover soil evaporation losses are minimal. Ineffective evaporation as indicated in Figure 1 is the soil evaporation which occurred outside the growing season and evaporation of light, ineffective showers which occurred throughout the season.

Table 1: Run-off, drainage, growth effective rainfall (GER) and crop water-use efficiency (WUE) during 5 growing seasons under 3 different tillage systems.

Tillage System	Runoff mm	Drain. mm	GER mm	Yield t/ha	WUE [a] kg/m³
1988/89 Seasonal rainfall = 414mm					
Conventional tillage	10.2	108.6	199.9	2.5	1.3
Mulch rippping	3.9	98.6	204.2	3.0	1.5
Tied ridging	0.2	67.0	198.9	2.2	1.1
1989/90 Seasonal rainfall = 748mm					
Conventional tillage	151.0	nd	nd	6.6	nd
Mulch ripping	28.9	nd	nd	7.4	nd
Tied ridging	24.6	nd	nd	6.7	nd
1990/91 Seasonal rainfall = 343mm					
Conventional tillage	55.0	93.3	120.8	1.7	1.4
Mulch ripping	1.1	111.6	149.5	2.8	1.9
Tied ridging	0.2	74.4	173.6	2.3	1.3
1991/92 Seasonal rainfall = 164mm					
Conventional tillage	1.6	0.0	98.5	0.0	0.0[b]
Mulch ripping	1.6	0.0	98.5	0.0	0.0[b]
Tied ridging	0.1	0.0	97.3	0.0	0.0[b]
1992/93 Seasonal rainfall = 692mm					
Conventional tillage	117.5	146.8	302.1	5.8	1.9
Mulch ripping	34.7	240.0	283.0	7.3	2.6
Tied ridging	22.0	173.5	353.9	4.5	1.2

nd = no data available; [a] = related to GER and grain yield
[b] = crop failure due to drought

Growth-effective rainfall and yield
The relationship between GER and yield shows clearly that MR has the highest crop yield per mm GER followed by CMP (Figure 2 and Table 1). Despite a high percentage of the total rainfall being growth effective under TR, (Table 1) the water use efficiency (WUE) is lower. WUE differences are particularly more pronounced during high rainfall years as compared to dry ones. Under drier conditions lower moisture contents on ridges result in an evaporation barrier at the surface (9). The yield differences at 200mm GER are up to 750 kg/ha, whereas at 250mm GER they are already at 2.8 t/ha while 300mm gives a staggering difference of 4.7t/ha. This finding reinforces the previously mentioned fact that the WUE by TR is lowest and that the E_T value comprises a higher percentage of soil evaporation compared to the other treatments. The reverse of this is true for MR where GER is lowest and WUE highest. Regression analysis of the two parameters for the different treatments was found to be highly significant and R^2 was 0.95 for

CMP, 0.93 for MR and 0.94 for TR. These facts do not, however, mean that TR produces lower yields. As mentioned above (Figures 1) the percentage of GER is highest in TR (Table 1). Equal and even higher yields on TR compared to CMP have been found in on-farm trials (11, 12) where up to 23% more yield was obtained from TR during the 1992/93 season.

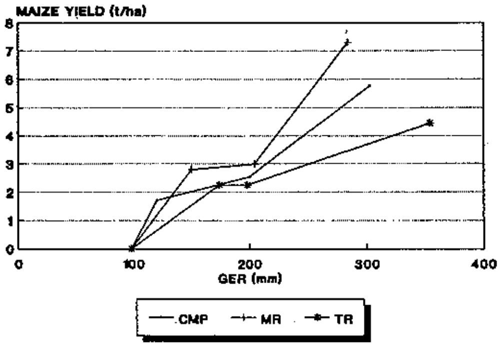

Figure 2: Relationship between GER and yield for three tillage systems over 5 seasons (1988/89 - 1992/93).

Crop water use efficiency ratios
The WUE ratios were calculated and showed that MR has by far the highest WUE (Table 1), followed by conventional tillage and lowest by tied ridging. This shows that the available soil water is most effectively utilised by plants under the mulch ripping treatment.

This simple method was found to be appropriate in quantifying soil water balance. During the 1992/93 season drainage was also measured with lysimeters (13). The values obtained with lysimeters and with water balance calculations corresponded well. This indicates that the applied method produces reasonable results in sandy soils. The underlying concept of functional field capacity (9) is applicable to these sands with their low unsaturated hydraulic conductivity. In future work, the method will be verified with flux calculations using measurements of the matric potential.

CONCLUSION

From a water balance point of view MR with its high water use efficiency appears to be the most viable conservation tillage treatment in the semi-arid areas. Provided the high drainage losses from this treatment do not increase nutrient leaching drastically, high drainage can be considered a positive attribute as groundwater recharge is also an important factor. In the Communal areas of Zimbabwe, however, the present farming system limits its application as stover residues are utilised as fodder during dry seasons and remaining residues are grazed after harvest. In Communal Areas with a low livestock population, and in small and large scale commercial farming, the mulch ripping system should be given priority therefore. Considering high nutrient losses due to high run-off, soil loss and leaching in CMP, TR with its minimal soil loss and reduced nutrient loss to leaching (13) appears as an applicable conservation tillage option to CMP, which can curb water and soil losses in a sustainable way.

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THE EFFECT OF WATER MANAGEMENT ON CROP PERFORMANCE IN THE VERTISOLS OF SUDANO-SAHELIAN NIGERIA.

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ABSTRACT

The first phase of a field experiment to determine the effect of water management - broad beds drained by 1m furrows (BBF), flats and bunded flats - on rainfed yields of maize (*Zea mays*) Var. Wumbi, Sorghum (*Sorghum bicolor*) Var. ICSV III and cotton (*Gossypium* spp.) Var. S77, in the vertisols of sudano-sahelian Nigeria was conducted at Ngala from 1991 to 1993. The plots on the flats had higher bulk density and gravimetric soil moisture. Seedling emergence was influenced by the heaviness of the soil, soil type used for covering planting holes and moisture condition from seeding to crop emergence. Seedling emergence was generally enhanced by covering the planting holes with coarse to medium-textured soils. Crop vigour at the early stages depended more on the rainfall distribution pattern and less on the land shaping method but during the later stages, it depended on the method of water management. In general plant growth during the rains was better on the broad beds. Incidence of weeds was high in the flats and bunded flats but isolated in the BBFs. The results seem to indicate that 50% flowering or heading can be easily attained in the flats and bunded flats than on the BBFs in years when rainfall ceases in ≤ 45 days after planting. Tillage had a significant effect on root penetration. Average rooting depth of cotton was 23.1, 18.5 and 16.5 cm on the flats and 30.6, 22.7 and 19.1 cm on the BBFs (1991, 1992 and 1993 respectively).

INTRODUCTION

The vertisols of Sudano-Sahelian Nigeria are located in the Ngala and Marte plains and cover an area of 81,995 ha. The soils are used for irrigated winter wheat production and the more common sorghum known locally as Masakwa which grows on residual moisture. Very limited use is made of the soils for rainfed crop production as a result of the problems of water management and the difficulty of tilling them outside a narrow range of moisture contents.

Different promising systems to improve the surface drainage of vertisols have been studied. ICRISAT experience in India has indicated that effective surface drainage increased the productivity of vertisols (1). In Ethiopia, (2) reported that improving drainage on vertisols significantly increased crop yields (by planting them on 6 m wide cambered beds). According to (3), yields of food and feed crops increased substantially when planted on broad beds on vertisols as a result of improved drainage. The studies of (4) showed that the vertisols of Sudano-Sahelian Nigeria are promising as potential for rainfed food and feed production if properly managed.

In this study, the effect of water management - broad beds and furrows, flat, and flat with bunds-on the performance of rainfed maize, sorghum and cotton are being assessed.

MATERIALS AND METHODS

The first phase of the study was conducted at Ngala in the Lake Chad area to the North East of Maiduguri (Fig.1).

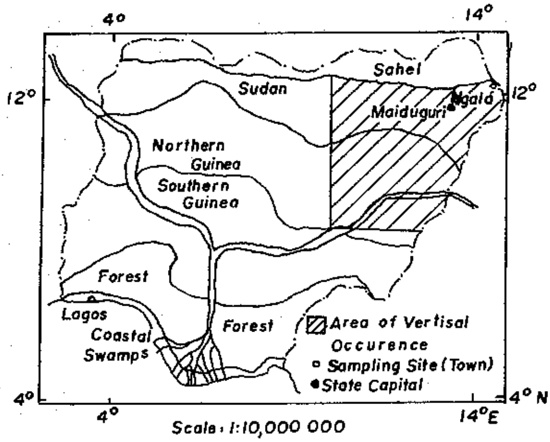

Figure.1 Map Showing the location of the Study area

Ngala is a featureless clay plain with slope of 0-2% and is about 289 masl. The annual precipitation varies from 174 to 713 mm. The soils are dark gray, Montmorillonitic, isohyperthermic, ustic, typic pellusterts developed from Quaternary lacustrine deposits and are underlain by light brownish gray sands. Their physical and chemical characteristics indicate a high level of fertility (Table 1).

Table 1. Some physical and chemical properties of the soils

Depth (cm)	pHw 1:2.5	OC %	N %	Av.P mg kg^{-1}	Ca ----	Mg cmol	K (p+)	Na kg^{-1}	ECEC ----	Bulk density mg m^{-3}	
			Broad beds								
0-15	7.1	0.6	0.04	18.8	20.8	5.1	2.4	2.9	31.3	1.24	
15-30	7.5	0.5	0.04	13.1	23.8	5.3	2.6	3.3	35.2		
			Flats								
0-15	7.4		0.6	0.04	20.9	20.3	5.0	2.5	2.6	30.5	1.42
15-30	7.4	0.5	0.05	12.3	21.1	5.2	2.6	3.1	32.2		

Sand = 10%, Silt = 18%, Clay = 72%, Textural class = clay,
Shear strenght = 122.0 KN m^{-2} Soil classification:
Typic Pellustert (USDA: Eutric Vertisol (FAO)

An experiment was conducted from 1991 to 1993 in a previously characterized site. It employed a randomized complete block design with 4 replications. Treatments initially were farmers practice (Flat-planting on the flat) and broad beds drained by 1m furrows (BBF). As a result oflessons learnt from the trial in 1991 and 1992, a third treatment Bunded Flat (FB) was included for water conservation or removal depending on the rainfall and its distribution. Individual plots were 5 m wide and 10 m long. The test crops-maize, sorghum and cotton-were planted with spacings of 90 x 40, 90 x 30 and 90 x 45 cm respectively. The maize and sorghum were fertilized with NPK (15:15:15) at the rates of 400 and 427 kg ha^{-1} respectively while cotton received 110, 140 and 33 kg ha^{-1} of urea, SSP and MOP respectively.

Total amount of rainfall was 638.90, 335.15 and 500.80 mm respectively for 1991, 1992 and 1993. The monthly rainfall distribution during the period is presented in Figure 2.

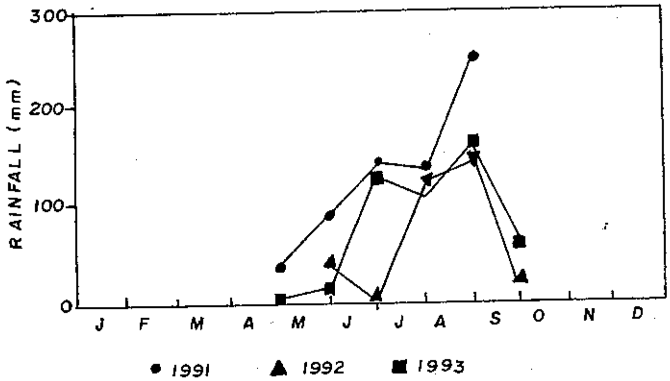

Figure. 2, Monthly rainfall for Ngala

RESULTS AND DISCUSSION

Crop Establishment

The establishment of the crops was significantly (Table 2) affected by the treatments, method and time of seeding and moisture condition from seeding to crop emergence. The data suggest that germination failure could result from planting sorghum directly into the soils. For a good sorghum establishment, it seems better to raise the seedlings in a medium or moderately coarse textured soils (foreign soil) and later transplant to the field. The transplanted seedlings established easier on the flats and BBFs than in the BPs because of water logging problems in the latter at the time of transplanting.

From Table 2, it appears that germination can be greatly enhanced by covering the planting holes with foreign soil. The BBFs promoted easier germination of the crops when planting was delayed till the establishment of the rains. There was no significant difference in the germination of maize and sorghum in both BBFs and flats when they were dry-seeded after the initial rains.

Table 2a. Yield and yield components of maize

Treatments	%Germination 1991+	1992++	1993*	Height cm 1993	Grain yield /plant g 1993
BBF	96.6	89.0	10.5	79.7	
Flat	24.1	95.7	35.2	86.7	10.9
FB			34.1	100.4	11.9
LSD 0.05	13.0	NS	11.7	19.0	NS

+Direct seeding and covering with foreign soil after rainfall establishment
++Dry seeding and covering with foreign soil after first few rains
*Direct seeding and covering with soil in situ after rainfall establishment

Table 2b. Sorghum establishment and height

Treatments	% Germination 1991+	1992+	1993**	Height (cm) 1993
BBF	0	20.4	40.4	49.5
Flat	0	19.0	62.6	67.8
FB			27.7	61.5
LSD 0.05		NS	17.80	10.14

**Seedling raised on foreign soil and later transplanted
+Direct seeding and covering with foreign soil after rainfall establishment

Table 2c. Cotton establishment and root length.

Treatments	% Germination 1991	1992	1993	Root length (cm) 1991	1992	1993
BBF	72.9	73.1	6.4	30.6	22.7	19.1
Flat	16.1	66.6	6.0	23.1	18.6	16.2
FB			6.0			16.2
LSD 0.05	30.7	6.0	NS	7.0	NS	NS

Crop Vigour, 50% Flowering and Incidence of Weeds

Plant growth during the rains was significantly better on the BBFs. After the cessation of rains, the growth of crops became more vigorous in the FBs and flats than in the BBFs. The excess moisture (Table 3) stored in the FBs and flats as a result of water logging during the rains was used by the plants after the cessation of rains. This could be responsible for the earlier flowering and tasselling of cotton and maize respectively in those plots. The sorghum in the flat headed earlier than others.

The incidence of weeds was higher in the FBs and flats but isolated on the BBFs. However, the incidence was high in the broad bed furrows.

Table 3. Moisture content of the plots at 7 WAP.

	Moisture content 0 g (g g^{-1})					
Treatment	0 - 15 cm		15 - 30 cm		30 - 50 cm	
	1992	1993	1992	1993	1992	1993
BBF	0.19	0.17	0.23	0.21	0.28	0.26
Flat	0.21	0.19	0.25	0.29	0.30	0.36
FB*		0.19		0.23		0.29

* Not a treatment in 1991 and 1992

Plant Height

As a result of the failure of the improved maize variety (TZESR-W) in 1991 and 1992 due to early cut-off of rains, a local variety (Wumbi) was planted in 1993. The data (Table 2a) show that there were significant treatment differences in plant height. The maize plants in the FBs and flats were taller. Sorghum plants in the flats were taller than those in the FBs and BBFs. This could be due to the differences in moisture conditions at the time of transplanting and their effect on the establishment.

Seed Cotton and Maize Yields

The three years records showed that cotton may not reach full maturity if planting is delayed till the rain is well established. There was no clear trend in the yield of cotton among the treatments but the data from the few stands that flowered in 1992 and 1993 suggest that cotton planted on flats and FBs may outyield those on BBFs in years when rainfall ceases early.

The maize cobs on the flats and FBs had grains while there was no grain filling in the cobs on BBFs. This may be due to the later utilization of the stored water in the flats and FBs unlike in the BBFs where excess water was drained away. There was no significant difference in the yield of maize in the FBs and flats probably because of the timing of the opening and closing of bunds to release or conserve moisture. The transplanted sorghum headed but could not reach full maturity.

Root Observations

From Table 2c it appears that tillage had a significant effect on root penetration. Cotton roots penetrated to relatively greater depths in the BBFs than in the flats and bunded flats. This could be related to the bulk density of the soils (Table 1). The data showed a decrease in root penetration in the treatments over the years. The decrease in the flats is possibly due to differences in depth of tillage while that in the BBFs is due to soil settling.

FUTURE RESEARCH

This will involve planting immediately after the first few rains, soil moisture profile studies and deeper tillage.

ACKNOWLEDGEMENTS

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EFFECTS OF DIFFERENT TILLAGE PROCEEDURES ON THE SUBSOIL STRUCTURE OF DEEP-LOOSENED RECLAIMED LOESS SOILS

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ABSTRACT

The general goal of the investigations was to protect the weak structure of dry restored, graded and deep-loosened loess soils of reclaimed coal mines against compactive forces caused by soil tillage. Therefore, the stress distribution and the failure behaviour of the soils during tillage were measured. Turning the earth by heavy ploughing combinations (136 kW tractor, 4 and 5 shares) induced high vertical and deviatoric stresses down to a depth of 85 cm. Ploughing with smaller combinations (85 kW tractor, 3 shares) reduced vertical stresses but did not significantly affect the input of deviatoric stresses. A significant decrease of deviatoric stresses was measured using a combination of heavy tractor (136 kW) and small plough (3 shares). Non-turning, cultivating tillage systems strongly reduced vertical and deviatoric stresses compared with ploughing, but deviatoric stresses also caused shear failure because of the low shear strength of the soil. The lowest deviatoric stresses were measured under a sowing combination.

INTRODUCTION

After restoration, the loess soils in the western german brown coal district are graded by bulldozers. When they are conventionally graded by small tracked bulldozers, grading produces strong compacted layers down to 90 cm soil depth, which are ameliorated by chisel-lift-looseners. When the soils are alternatively graded by wide-tracked bulldozers, structure remains loose and deep-loosening is not necessary (1).
Nevertheless, wether the soils are softly graded or hardly graded and deep-loosened, soil structure of the restored soils is very weak and soil strength is very low (2).
In order not to damage soil structure by the impact of tillageing forces, different tillage systems for cropping corn were compared with respect to the input of vertical and deviatoric stresses that induce compression and shear failure to the soil structure.

MATERIALS AND METHODS

Measurement of soil stresses
Soil stresses were measured with the "Stress State Transducer" (SST) according to (3). The sensor registrates six normal stresses out of which the principle stresses (σ_1,σ_2 and σ_3) are calculated. The deviatoric stress state in an octahedral plane is given by the "Octahedral Shear Stress" (OCTSS) as:

$$\text{OCTSS (kPa)} = \sqrt{\frac{2}{9}\left((\sigma_1 + \sigma_2 + \sigma_3)^2 - 3\,(\sigma_1\sigma_2 + \sigma_2\sigma_3 + \sigma_1\sigma_3)\right)}$$

The normal stress state in the octahedral plane is given by the "Mean Normal Stress" (MNS) as:

$$\text{MNS (kPa)} = (\sigma_1 + \sigma_2 + \sigma_3)/3$$

Estimation of soil failure

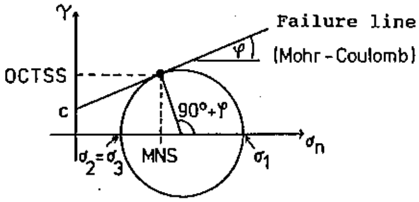

Figure 1: SST-Shear Stress Diagram to estimate shear failure, depending on octahedral shear stress (OCTSS), mean normal stress (MNS), cohesion (c) and angle of internal friction (φ).

The shear failure behaviour of the soil is estimated by comparing the calculated values of OCTSS and MNS with the Mohr-Coulomb failure criterion in a "SST-Shear Stress Diagram" according to (4). When the combination of OCTSS and MNS is below the failure line, soil structure remains stable (Fig. 1). When the combination is on or above the line, shear failure occurs to the structure.
The shear strength parameters and the pre-compression stress were measured consolidated, drained at undisturbed soil cores.

Tillage proceedures
The tillage proceedures were seven plough systems, two differently wide cultivator systems and one sower system (Fig. 2). The plough systems were different in driving technique, number of shares, tractor power, axle load and tires.

	Ploughing							Cultivating		Sowing
technique	conv. furrow		on site	reduced furrow				wide	small	harrow + sower
No. of shares/width	4	3	5	4	3	3	3	5.60 m	3.60 m	4.00 m
Power (kW)	85		136	136	136	85	85	136		114
Tires	normal		wide	wide	wide	wide	cultiv.	wide		wide
Wheel load (kg)	1475		1997	1997	1997	1830	1427	1997		1997
Contact pressure (kPa)	43		49	46	46	43	63	47		47

Figure 1: The different tillage proceedures.

The soil stresses were measured by three stress sensors in each depth under the centre of the rear wheel track or the rear furrow wheel track of the plough systems.

RESULTS

The impact of vertical stresses into the soil through the heavy plough systems (4 and 5 shares) is significantly higher than that caused by the smaller 3-share systems (Fig. 3). The stresses of the heavy systems significantly exceed the pre-compression stress, that indicates the vertical soil strength, to greater soil depth than those of the lighter systems.
Within the heavier systems, conventional ploughing caused higher stresses than the techniques with on site and reduced furrow driving.

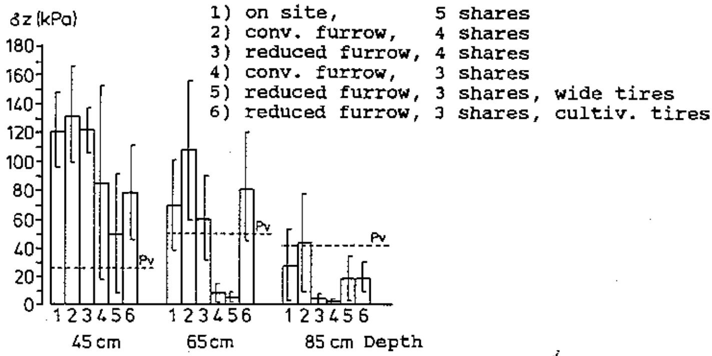

Figure 3: Impact of maximum vertical stresses (σ_z) through different ploughing systems (Pv = pre-compression stress, soil water tension: ca. 300 hPa).

The different required tractive power of the different tillage systems strongly affects the impact of vertical stresses (Fig. 4). Using tractors with equal axle load and nearly equal power, the sowing combination causes lower stresses than the systems with cultivator and plough.

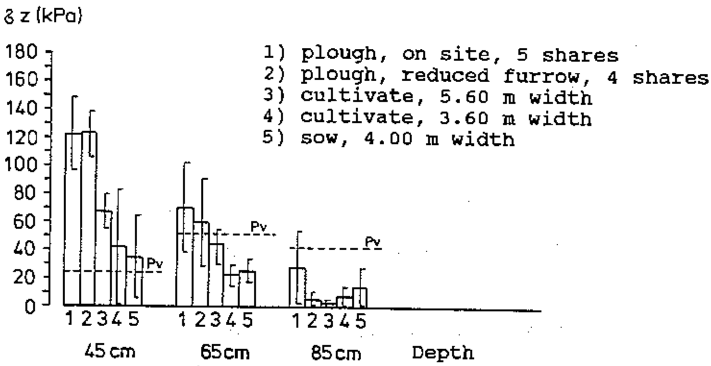

Figure 4: Impact of maximum vertical stresses through different tillage systems (Pv = pre-compression stress, soil water tension: ca. 300 hPa)).

The deviatoric stress situation in the soil under the various plough combinations is very different to that of the vertical stresses (Fig. 5). The octahedral shear stresses induced by the smaller systems are not reduced compared with those of the heavier systems. Nearly all combinations of octahedral shear stress and mean normal stess under both, heavy and light ploughing systems, induce shear failure to the soil structure.

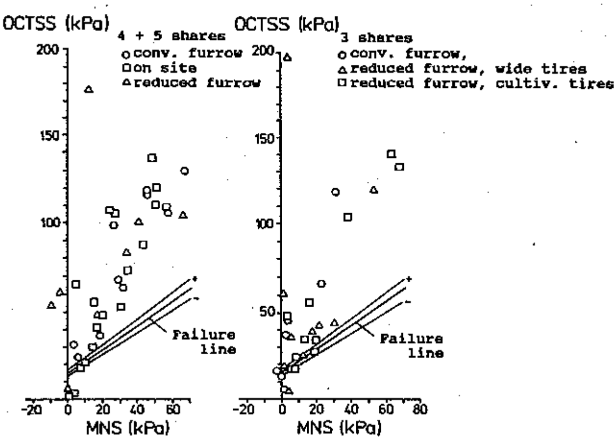

Figure 5: SST-shear stress diagram of octahedral shear stress (OCTSS) and mean normal stress (MNS) at the moment of maximum stress input through the different ploughing systems.

The impact of deviatoric stresses through the different tillage systems, run with nearly equal powered tractors, was strongly affected by the required tractive power (Fig. 6).

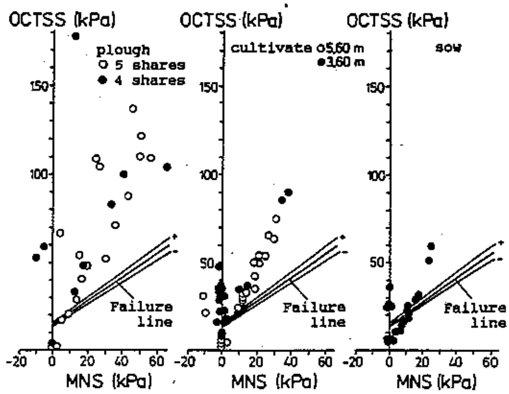

Figure 6: SST-shear stress diagram of octahedral shear stress (OCTSS) and mean normal stress (MNS) at the moment of maximum stress input through different tillage systems.

Cultivating strongly reduced the impact of deviatoric stresses compared with the heavy plough systems, especially with the smaller working width of 3.60 m. Nevertheless, the octahedral shear stresses through cultivating predominantly induced shear failure to the soil structure, due to the low shear strength of the weak soil. Only the sowing proceedure decreased shear failure of the weak soil structure to larger extent.

A surprising result in Figure 5 was the high impact of deviatoric stresses by the smaller plough systems, even though the required tractive power was reduced. Compared with the heavier 4- and 5-shared systems, the 3-shared systems were run with tractors of lower power. Figure 7 shows the comparison of stress input by different wide plough systems using the same tractor (136 kW). The 3-share combination increases soil stresses only in 45 cm depth, compared with the net tractor. The same tractor with the 4-shared plough strongly increased both, vertical and deviatoric stresses in the soil.

The vertical stresses of the smaller plough system were even lower in 45 cm depth than those of the sowing combination, that has a lower required tractive power. However, the circle harrow of the sowing combination was not supported by own wheels but was hanging on the rear axis of the tractor and, therefore, induced higher vertical stresses.

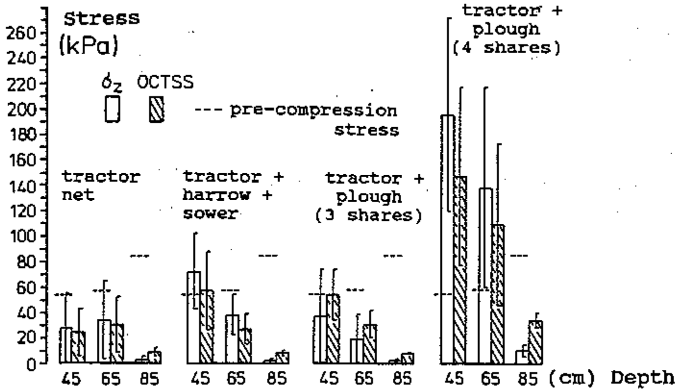

Figure 7: Impact of maximum vertical stresses (σ_z) and octahedral shear stresses (OCTSS) into the soil through a net tractor, two different plough systems with the same tractor (reduced furrow) and the sowing combination (soil water tension: ca. 60 hPa).

DISCUSSION

Reductions of axle load and tractive power are discussed worldwide as a measure to protect soils from compaction. Soil compaction is predominantly affected by two different stress components: the vertical and the deviatoric stress.
The vertical stress is closely related to bulk density. When the vertical stresses exceed the pre-compression stress, bulk

density of soils is increased and other soil physical properties are changed (5). The results of Figures 3,4 and 7 show, that the reduction of wheel load and tractive power significantly reduce the impact of vertical stresses and therefore, is a measure to protect the soil structure from vertical compression.

Shear failure of soil structure due to deviatoric stresses does not inevitably increase bulk density, but changes soil pore structure. Dilatancy deformation by shear failure can influence hydraulic conductivity, air capacity and water capacity but may not affect bulk density (2). Figures 5 and 6 show, that the reductions of axle load and tractive power do not significantly reduce the deviatoric stresses when the traction capacity of the tractor is also reduced. Figure 7 shows, that a decrease of deviatoric stress input through reduced tractive power could only be realized when the traction capacity of the tractor was kept high. Therefore, protection of weak soils from shear failure can only be obtained with reduced slip when the traction capacity is not completely used up.

Generally, the results show, that heavy ploughing should be avoided on weak, deep-loosened soils (6). Alternative tillage techniques as cultivating and direct sowing should be preferred. If ploughing is inevitable, soil structure is most protected from compaction by alternative driving techniques as on site and reduced furrow driving, high traction capacity and low required tractive power.

CONCLUSIONS

1) Protection of weak soils structure from vertical compression is generally obtained by reductions of axle load and tractive power.

2) Protection of weak soils structure from shear failure is only be reallized when tractive power is reduced and traction capacity is kept high.

3) In weak, deep-loosened soils heavy ploughing should be avoided and cultivating and direct sowing should be preferred.

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THE VARIATION OF CRITICAL-STATE PARAMETERS WITH WATER CONTENT FOR TWO AGRICULTURAL SOILS

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ABSTRACT

Triaxial tests were conducted on 301 reconstituted samples of two soils at moisture contents from air dryness to close to the respective liquid limits. Volume change behaviour was largely consistent with the critical-state concept, the role of soil moisture content being expressed in the values of the measured critical-state parameters. The most important parameters, and their inherent variability, are specified. The parameters varied systematically with soil moisture content but differently for the two soils. Some of the parameters were closely linearly correlated. The implication of this ordered behaviour is discussed.

INTRODUCTION

At least three early reviews of basic elements of the critical-state concept, originally developed for saturated soils, point out its potential relevance in explaining the volume change and failure behaviour of unsaturated soils (Kurtay & Reece, 1970; Reece, 1977; Hettiaratchi & O'Callaghan, 1980). Details of a model adapted to agricultural soils are set out by Hettiaratchi (1987, 1988). Qualitative agreement with elements of the critical-state model of soil deformation has been demonstrated in studies based on triaxial compression tests and in studies based on uniaxial compression and direct shear tests (see references in Petersen, 1993). Very few measurements dealing with the quantitative effects of soil moisture content have been presented in the literature related to agricultural soils.

The critical-state theory relates mean normal stress, p and deviatoric stress, q to specific volume, v. Fig. 1 shows the probably familiar state boundaries in state space. The volume change behaviour of a soil at a particular moisture content is uniquely defined by a few parameters describing elastic behaviour and the state boundary surfaces.

The objective of the present study was to evaluate the critical-state concept at different soil moisture contents and to present and analyse important critical-state parameters and their variation with water content.

MATERIALS AND METHODS

Two soils, a sandy loam (soil T) and a loam (soil M) were passed through a 2-mm sieve, air dried and stored at constant air temperature and humidity. Reproducible, relatively loose samples were formed by spoon feeding known amounts of soil into cylindrical formers. The samples were slowly wetted to zero soil moisture tension and then brought into a cemented state by adjusting the tension. The samples were carefully trimmed (height: 80-83 mm; diameter: 83 mm) and then stored in watertight plastic bags until used in the testing.

A triaxial test apparatus under computer control was used to apply gradually increasing stress levels following one of three different ways of stress loading. All tests were initiated by hydrostatic loading leading the soil into a normally consolidated state. From this state the soils were subjected to continuously increasing shear loading maintaining either a constant confining pressure, $\sigma_2=\sigma_3$, a constant mean normal stress, p, or a constant sample volume. The stresses were applied at variable rates, but always so slowly that the rate was unimportant. The stress levels were varied as much as possible ($p \leq 800$ kPa) considering that the degree of water saturation should never be large enough to hinder the free escape of air.

Friction between a triaxial sample and the end platens during a compression test may cause the formation of dead zones adjacent to the platens resulting in a non uniform distribution of stress and strain (Head, 1986, p. 1054). In the present study restraint at the sample ends was greatly reduced by lubricating the end platens as described by Head. The uniformity of deformation with lubricated ends and a 1:1 ratio of sample height to sample diameter tended to cause the homogeneous soils to fail in a plastic manner, or on multiple failure surfaces, rather than on a single prematurely developed failure surface. Volume change and stress state measurements made during compression are therefore believed to relate to the sample as a whole rather than to one particular zone.

Sample length, confining pressure, axial force and changes in water content of the triaxial test chamber were measured by commercially available transducers. Bulk density was calculated from oven dry mass, initial sample dimensions and sample volume changes during the test. Changes in sample volume was derived from the amount of water moving into or out of the test chamber with corrections for expansion of the chamber with pressure increase and for displacement of water by movement of the loading ram as described by Head (1986, p. 900). p and q (expressed in kPa) were calculated from total (principal) stresses applied at the soil boundaries. Stresses were corrected for changing contact area at the sample ends due to axial strain (the 'barrelling' correction) and to changes in sample volume as described by Head (1986, p. 890).

RESULTS AND DISCUSSION

Calculations for both soils at all water contents (see Fig. 2) on the data representing normal compression showed that v and $\ln(p)$ were always closely linearly correlated, the typical coefficients of correlation being between -0.990 and -0.999. The usual equation for NCL:

$$v = N - \lambda \ln(p) \tag{1}$$

being in accordance with the critical-state formulation was therefore generally accepted. Calculated least-square estimates of the parameters N and λ were compared to replicate tests for the same soil and water content to identify tests that were outliers. The replications (at least 5) were used to calculate an estimate of the mean and standard deviation for each parameter. Outliers were omitted in further analyses if any of the estimated parameters were not within the acceptable range given by Chauvenet's criterion for normally distributed data. Most rejections were because of parameter N. Mean values and standard errors for N and λ

found when rejecting up to two outliers for each combination of soil and water content are shown in Figure 2.

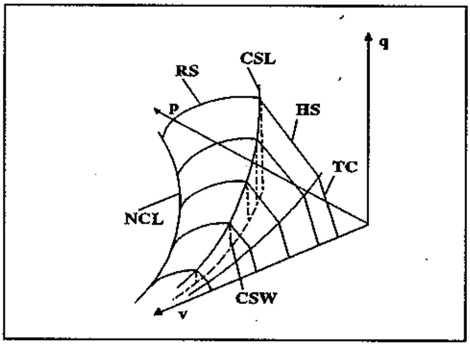

Figure 1. State-boundary surfaces in p-q-v-space. CSL: critical-state line; NCL: normal consolidation line; CSW: critical-state wall; RS: Roscoe surface; HS: Hvorslef surface; TC: tension cut-off surface.

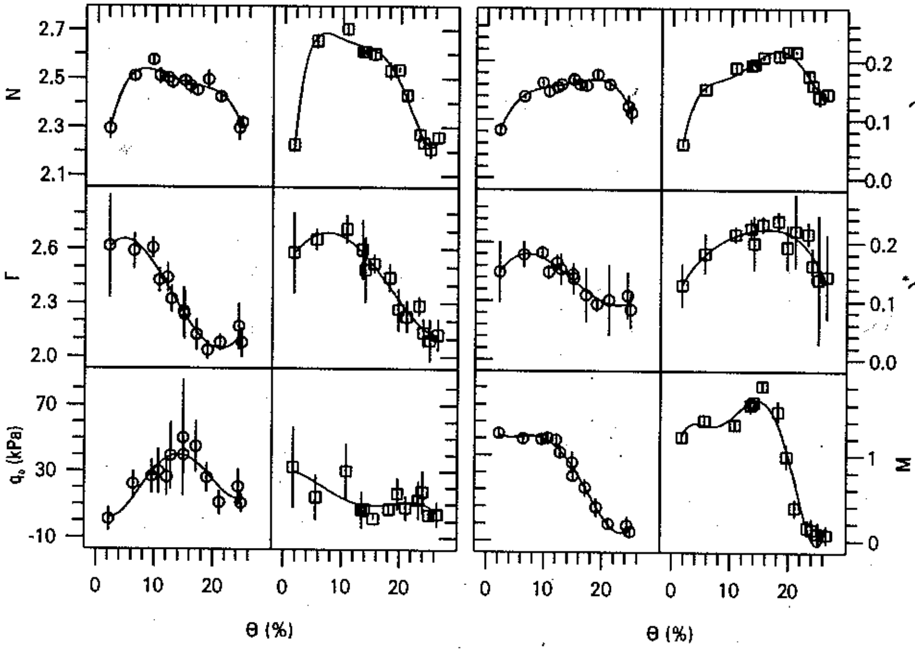

Figure 2. Critical-state parameters plotted versus gravimetric water content for soil T (○) and for soil M (□). The results are smoothed by a fourth- or a fifth-degree polynomial whichever fitted the data points best. Bars: parameter estimate ± 2*standard error.

Data representing critical states were readily identified. Usually there was a close coincidence between a situation of constant (or nearly constant) stress and zero (or very small) rate of volumetric strain which remained unchanged for some time. Readings in such situations were selected as representing critical states. The critical states were reached at axial strains between 0.15 and 0.48 cm cm^{-1}. The equations:

$$v = \Gamma - \lambda^* \ln(p) \tag{2}$$
$$q = q_0 + M\,p \tag{3}$$

with the parameters Γ, λ^*, q_0 and M were fitted to data representing critical states for each combination of soil and water content. The equations define the locus of the CSL in the p-q-v-space and, therefore, the mode of failure (brittle or ductile), according to critical-state theory. Where possible, depending on number of tests, separate equations were fitted for each of the different types of loading and the regression lines were compared by successively comparing the slopes and levels. The hypothesis of a unique critical-state line for each combination of soil and water content as expressed by Equations (2) and (3) was rejected on the 95% level for soil T at three water contents out of twelve and for soil M at two water contents out of eleven. Four of these rejections were due to different Γ-values. The largest Γ-values, in all these four cases, were found for the load path with constant confining pressure indicating some sort of systematic error. The results did not indicate that the rejections had any systematic connection with soil type or water content. Many more experiments would have been needed to prove or disprove the hypothesis comprehensively. However, the finding that it is difficult or impossible to reject the hypothesis of a unique critical-state line is in agreement with results from triaxial tests published by Bailey & VandenBerg (1968) for four different soils, each at one single water content. The finding is also in agreement with Kirby (1991) who used constant normal stress and constant volume tests in a shear box experiment and showed that the two gave similar results. The parameters Γ, λ^*, q_0 and M with standard errors shown in Figure 2 were calculated without considering type of loading.

The traditional critical-state theory specifies that the projection of CSL on the p-q-plane should pass through the origin. The hypothesis $q_0=0$ was rejected on the 95% level for all but four combinations of soil and water content. The existence of an intercept is very likely due to the formation of interparticle bridges and may be a direct consequence of describing the stresses in total rather than effective terms. Similar and even greater intercepts than found in the present study were reported by Bailey & Johnson (1988) working with remoulded soils whereas Hettiaratchi (1987) reported on small intercepts, but only for cemented soils.

It appears that the critical-state parameters vary systematically with soil moisture content except perhaps for q_0 for soil M. The small increase in λ and decrease in N with θ up to large θ values is in accordance with results published by Leeson & Campbell (1983). Hettiaratchi & O'Callaghan (1985) suggest that the position of the normal consolidation line on the v-$\ln(p)$-plane alters in an ordered fashion with water content. They suggest that the NCLs corresponding to the different water contents for most soils have a fixed pivot point $(\ln(p_0), v_0)$ on the $\ln(p)$-v-plane where $p_0 \approx 10$ kPa independently of soil type whereas v_0 depends on soil type. The finding is interesting because it effectively reduces the number of critical-state parameters. It can easily be deduced that a fixed pivot point as described should exist if the parameters N and λ are linearly dependent on each other. However, N and λ are not very closely linearly correlated for any of the two soils in the present study, although the coefficients of correlation covering the whole range of water content are significantly different from zero (Table 1). Thus, the present results do not indicate the same ordered behaviour as suggested by Hettiaratchi & O'Callaghan.

Table 1. Correlation coefficients between critical-state parameters calculated for the whole range of water content. Coefficents for soil T and soil M above and below the diagonal, respectively.

Soil T Soil M	λ	N	λ^*	Γ	M	q_o
λ		0.81[a]	0.07	- 0.30	- 0.01	0.73[a]
N	0.61[a]		0.55[a]	0.26	0.50	0.59[a]
λ^*	0.84[a]	0.69[a]		0.91[a]	0.92[a]	0.19
Γ	- 0.01	0.73[a]	0.38		0.89[a]	- 0.17
M	0.24	0.81[a]	0.50	0.86[a]		0.18
q_o	- 0.47	- 0.02	- 0.27	0.41	0.08	

[a] Significant at least on the 95% level.

When reviewing results from triaxial tests carried out on remoulded samples from three different soils, Hettiaratchi & O'Callaghan (1985) found that λ^* and Γ varied in phase with each other for varying water content. While the present results for soil T do show that ordered behaviour, λ^* and Γ being closely linearly correlated (r = 0.91, cf. Table 1), results for soil M do not. Irrespective of soil type, Hettiaratchi & O'Callaghan found that the critical-state line projections on the $\ln(p)$-v-plane for the different water contents converged at a common $(\ln(p_o), v_o)$-point around (7,1.5). Hettiaratchi (1987) suggests that the p_o-value of the pivotal point depends on the microstructural state (cemented or remoulded) of the test sample. From λ^* and Γ values estimated for soil T in the present study it can be calculated that $\ln(p)$ for 83% of the intersections is approximately normally distributed around a mean $\ln(p)=5.4$ with a standard deviation of 3.8. For soil M there is no indication of convergence of the critical-state line projections on the $\ln(p)$-v-plane.

Referring to the Coulomb equation, the parameters M and q_o, obtained under triaxial test conditions ($\sigma_2=\sigma_3$) are of the form $M = 6\sin(\varphi)/(3-\sin(\varphi))$ and $q_o = 6c\cos(\varphi)/(3-\sin(\varphi))$ where φ is the apparent internal friction angle and c the apparent cohesion for failure occurring on the critical-state line (Head, 1986, p. 1093). Thus, M is a frictional parameter whereas q_o depends on the cohesion and to a small extent on the friction angle. For soil T M gradually falls with increasing water content, whereas for soil M M falls steeply in the narrow range between θ = 18 and 22% (Fig. 2). Similar marked falling off in the frictional properties of the more clayey soils have been reported by Hettiaratchi (1987).

In addition to the linear correlation between Γ and λ^* already mentioned for soil T, Γ and M are linearly correlated for both soils. It is, however, difficult to deduce the geometrical significance of this ordered behaviour.

CONCLUSIONS

The volume change behaviour for the two soils found at different moisture contents was largely consistent with the critical-state theory. It was generally not possible to distinguish between critical-state lines obtained from three different anisotropic stress load paths with constant σ_3, constant p, and constant v, respectively. The linear projection of CSL on the p-q-

plane showed, except in very few cases, a positive intercept on the q-axis. The critical-state parameters N, λ, Γ, λ^*, M, and (for soil T) q_0 varied systematically with soil moisture content. Clear differences in parameters were found between the two soils. λ^* and Γ were closely linearly correlated for soil T but not for soil M while for both soils Γ was closely correlated with M.

LIST OF SYMBOLS

σ_1, $\sigma_2=\sigma_3$	principal (total) stresses applied at the soil boundaries
$q = \sigma_1-\sigma_3$	deviatoric stress
$p = (\sigma_1+2\sigma_3)/3$	mean normal stress
$v = \rho_s/\rho_b$	specific volume
ρ_s	density of solids
ρ_b	dry bulk density
θ	gravimetric water content
λ	slope of normal consolidation line (NCL) on log-linear plot
N	specific volume specified by NCL at p = 1 kPa
λ^*	slope of projection of critical-state line (CSL) on log-linear plot on q=0 plane
Γ	critical specific volume specified by CSL at p = 1 kPa
M	slope of the projection of CSL on p-q plane
q_0	intercept on q-axis of the projection of CSL on p-q plane

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COMPUTER SIMULATION OF THE MECHANICAL BEHAVIOUR OF PARTLY SATURATED SOILS

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ABSTRACT Critical state space can be defined by a minimum of seven basic soil parameters, each of which is a function of both water content and the microstructural state of the soil. This profusion of variables is a severe deterrent to the proper perception of the systematic way state space geometry alters with the micro-structural state of a soil and, in particular, how it responds to changes in soil moisture status. Computer simulation of critical state space leads to a clear insight into both these factors. The development of software for this modelling is also the essential first step for making quantitative estimates of the volume change behaviour of partly saturated soils. The paper outlines the development of computer graphic images of critical state space and presents some preliminary results for three British soils.

1. INTRODUCTION

The critical state model of soil behaviour provides the Agricultural Engineer and Soil Scientist with a powerful tool for analyzing and understanding many aspects of field soil behaviour. From an engineering viewpoint this model is elegant in concept but it is somewhat lacking in refinement for dealing with practical problems. This model is fully capable of providing qualitative explanations of soil behaviour during engineering operations on agricultural soils [1]. The main parameters in this model are known for a variety of partly saturated agricultural soils [2 - 8]. The paper discusses how these parameters can be used in the development of computer models of critical state space of real soils. These models constitute the essential prerequisite for making quantitative estimates of the volume change behaviour of agricultural soils.

2. SPECIAL CONDITIONS FOR PARTLY SATURATED SOILS

2.1 Total and effective stress

In partly saturated soil the pore volume is occupied by air and water at their respective pressure u_a and u_w. The resulting curvature of the air water interfaces ensures that $u_w < u_a$ (soil water suction). The pore water in partly saturated soils does not carry any of the external loads and any change in pore volume has a negligible influence on u_w. The main role of soil water suction is to increase intergranular contact stresses in some complex manner [3,4].

The stress state variables relevant to unsaturated soils are $(\sigma - u_a)$, $(u_a - u_w)$ and τ [9]. In general, pore space in top soils has a free path to the atmosphere and hence $u_a = 0$. The stress variables thus reduce to σ, τ and $-u_w$. The magnitude of u_w for a soil at any specific volume v, is a function of its moisture content w. Critical state space discussed here is thus a function of w and the **total stress** components σ, τ. The variation of the relevant critical state parameters with w (or S_r) reflect the manner in which u_w controls the deformation and displacements taking place at the intergranular contact sites in the soil microstructure.

2.2 Moisture and stress history

The scatter in the measured values of critical state parameters of undisturbed samples is quite appreciable [6]. Triaxial compression tests on reconstituted soil samples appear to present the best compromise for obtaining representative values of the critical state parameters. A *remoulded* sample reconstituted at specific volume v_1 and moisture content w_1 can be made by mixing the required mass of distilled water with the appropriate dried mineral components of the soil. Alternatively a *cemented* sample at specific volume v_1 can be made up by drying a remoulded sample (say from saturation) down to the required moisture content w_1. Both these specimens have nearly identical values of v_1 and w_1, but because their stress and moisture histories are different their microstructural states, and their critical state parameters are not necessarily identical. In assessing published critical state parameters it is therefore essential to take into account the stress and moisture history involved in reconstituting the test specimens [4].

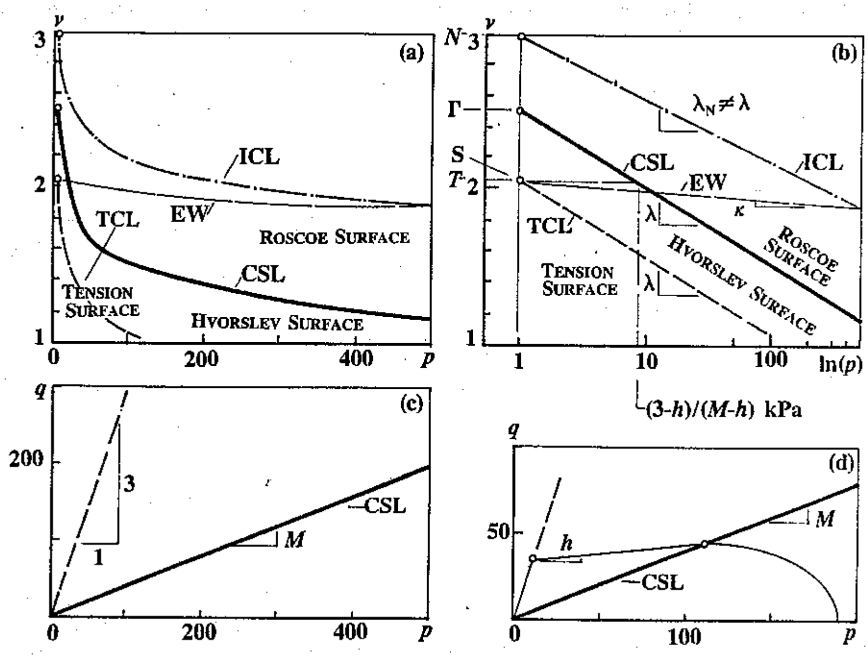

Fig.1 Projection of critical state space on q=0 plane:(a) linear plot, (b) log-linear plot. (c),(d) projection on stress-plane. Soil parameters for diagrams: N=3.0,λ_N=0.18; M=0.4,λ=0.2,Γ=2.5; h=0.1; κ=0.02; T=2.1; $S(p_i$=500 kPa)=2.0. All stresses are in kPa.

3. CRITICAL STATE PARAMETERS

The main features of the critical state model are well documented and will not be repeated here. In general the *state* of a soil is defined in terms of its pore space status (v) and its ambient total stress level [$p = ⅓(\sigma_1 + 2\sigma_3)$, $q = (\sigma_1 - \sigma_3)$].

3.1 Intersection boundaries between state surfaces

The Roscoe, Hvorslev and Tension surfaces of critical state space intersect in three distinct curves in p-q-v-space. The projections of these curves on the v-p-plane in Fig. 1(a) are the isotropic compression line (ICL), the critical state line (CSL) and the tension cut-off line (TCL). Note that in the literature the ICL has been variously designated as the virgin or normal consolidation line. The revised designation identifies this boundary from anisotropically compressed samples with $q = \eta p$, $\eta \neq 0$. The ICL is a special case of this when $\eta = 0$ (i.e. q = 0).

The linearised form of these curves on a v-ln(p)-plot [Fig. 1(b)] and their projections on the q-p-plane [Fig. 1(c)] provide the basis for quantifying these boundaries:

ICL: $v = N - \lambda_N \ln(p),\ q = 0;$ (1)

CSL: $v = \Gamma - \lambda\ \ln(p),\ q = Mp;$ (2)

TCL: $v = T - \lambda \ln(p),\ q = 3p.$ (3)

State paths of recoverable elastic deformations traverse on curved *elastic walls* (EW) within state space [Fig.1(a)]. Neglecting hysteresis effects, the projection of these walls on the v-ln(p)-plane also plot as a straight lines [Fig. 1(b)]:

EW: $v = S - \kappa \ln(p)$ (4)

3.2 Surface geometry of state space

Points on the Tension (TS) and Hvorslev (HS) state surfaces for any specified v are quantified as follows:

TS: $q = \eta\, p;\ \eta = 3$ (5)

HS: $q = (M - h) \exp[(\Gamma - v)/\lambda] + hp$ (6)

The parameter T in Equation (3) can be evaluated by putting $q = 3p$ in Equation (6):

$$T = \Gamma - \lambda \ln [(3 - h)/(M - h)] \tag{7}$$

It follows from Equations (2) and (7) that T $\equiv$ v on the CSL at $p = (3 - h)/(M - h)$ [see Fig. 1(b)].

According to the modified Cam-clay theory [10] for saturated soils ($\lambda_N = \lambda$) typical Roscoe surfaces, such as C_1I_1 and C_2I_2 in Fig. 2(a), project as ellipses on the q-p-plane with abscissa values ae = 2(ac) and ad = 2(ab). All such ellipses pass through the origin with bC_1 and cC_2 as their minor axes and their common major axes lie on the abscissa. However, for unsaturated soils ($\lambda_N \neq \lambda$) typical abscissa values such as *ae* are of the form *ae* = K(*ac*) where K is a function of v and not necessarily of magnitude 2. Not all the elliptical Roscoe surfaces are therefore required to pass through the origin [typical point *f* in Fig. 2(b)].

4. COMPUTER MODEL OF CRITICAL STATE SPACE

The seven soil parameters required for computing values of p,q and v for all points on the state surface are:

$N,\ \lambda_N;\ \ \Gamma,\ \lambda,\ M;\ \ \kappa;\ h.$

The value of T can then be obtained from Equation (7) and for any chosen value of v_i on the ICL the value of S for that particular EW is given by Equation (4). The pairs of co-ordinates

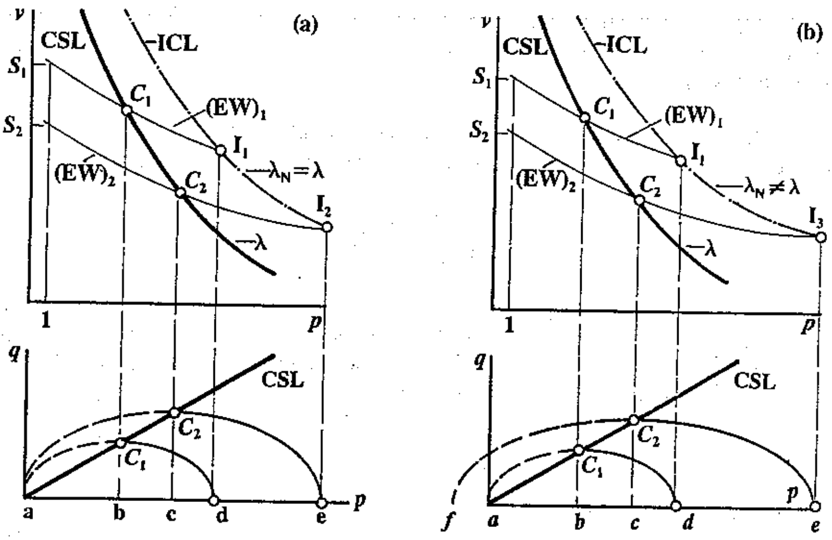

Fig 2. Development of Roscoe surface using modified Cam clay theory. Surfaces on curved elastic walls (EW) plot as ellipses on the stress plane (a). Saturated soil with $\lambda_N=\lambda$. (b) Partly saturated soil with $\lambda_N\neq\lambda$.

(p_c, v_c) and (p_t, v_t) where the EW intersects the CSL and the TCL respectively can be evaluated off Equations (1) - (6). The semi-major and semi-minor axes of the elliptical Roscoe surface are respectively $(p_i - p_c)$ and (Mp_c). The co-ordinates of the state surfaces are built up for values of p in the ranges (0 to p_t) for the Tension surface, (p_t to p_c) for the Hvorslev surface and (p_c to p_i) for the Roscoe surface.

This process simplifies somewhat if κ is set to zero so that $v_t = v_c = v_i = v$. This results in negligible distortion to the developed surface.Once values of p, q and v are known for a reasonably fine mesh a computer graphics package can be invoked to plot out all the state surfaces, complete with iso-stress contours of equal values of$p$ and q.

5. STATE SURFACES FOR REAL SOILS

Possibly the earliest attempt to evaluate critical state parameters for unsaturated soils was carried out at Newcastle in 1976 [11]. Since then the results of a number of more in depth investigations have been published [2 - 7]. Of these the most comprehensive set of results to appear in print is due to the painstaking investigations by Petersen [7]. An equally meticulous experimental investigation carried out by O'Sullivan [8] on three Agricultural soils is awaiting publication. There are no published records of data for values of h.

The composite drawing in Fig. 3 shows the computer generated state space of the soils described by O'Sullivan *et al.*[8]. Order of magnitude values of h were interpolated from separate experiments on similar soils [12]. Contours of equal p, q and v are shown on the state space diagrams for each individual moisture content. The variation of state space with soil moisture content is brought about rather dramatically. The following broad

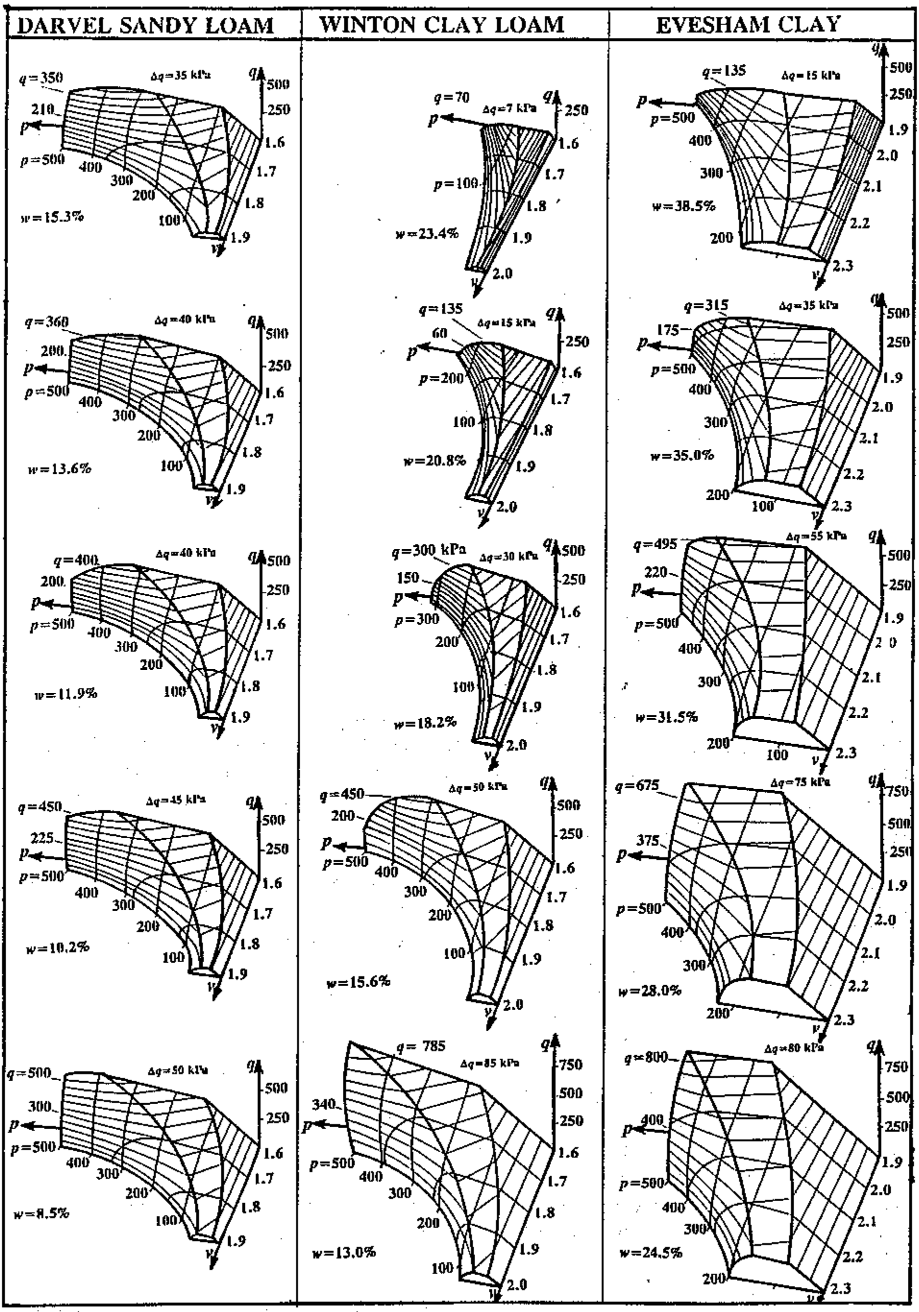

Fig. 3 Computer generated critical state space for three field soils. Soil parameters obtained from CCV [13] triaxial compression tests on 76mm dia. **remoulded** soil samples [8]. p and q are **total** stresses in kPa. Δq = contour interval; w = gravimetric water content.

conclusions can be drawn from this diagram:

(a) The state space proportions are least sensitive to moisture content in the sandy loam soil. Evidently clay content plays a significant part in this behaviour.
(b) The clay loam soil exhibits the largest variation in state space with moisture content.
(c) Comparatively speaking, the clay soil encloses the largest volume within state space. Elastic deformations are therefore significant, particularly in the dry state.
(d) Increase in moisture content swings the ICL, CSL and the TCL of all the soils towards the origin of co-ordinates in a systematic fashion.
(e) The tension surface is comparatively small in the loamy soils, but appreciable in the clay soil.
(f) In all three soils the slopes of the CSL increase as the soils dry out. This is indicative of a corresponding increase in the Mohr-Coulomb friction angle φ.
(g) The TS occupies a significant proportion of state space in the clay soil.This is particularly so for this soil in its dryer states and indicates a tendency to develop cracks on drying.
(h) The state space for the Winton soil at high moisture content is small indicating likely damage if worked very wet.

These observations are specific to the soils described here. However, a preliminary analysis of all the available data in this manner would suggest that these trends may be of general applicability. The logical extension of this modelling technique is the introduction of state path tracing for actual field operations.

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PORE-WATER PRESSURE DURING COMPRESSION OF BEDS OF UNSATURATED AGGREGATES OF SEVERAL CLAY LOAMS

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ABSTRACT

Soil centered measurements are needed to interpret soil structural responses to traffic/tillage induced stresses. Uniaxial stress influences on strain and pore water pressure in a bed of aggregates demonstrated a constant water saturation and bulk density at the minimum pore water pressure irrespective of initial water content. Stresses beyond this critical point of occluded interaggregate pore space deteriorated soil structure.

INTRODUCTION

Soil compaction is a major problem in both conservation and conventional tillage systems (1). Loads and ground pressures under tractor and carriage wheels are usually standard within large regions but differential soil response is often the expressed concern (1), especially when conservation tillage systems are used. At the interface of a tilled layer overlying a resistant subsoil, pressures of 30 to 100 kPa commonly occur at 30 to 40 cm (2,3); a moderate sized wheel tractor caused soil displacements at 30 cm below an annually plowed Ap layer (4), but there was also significant rebound at this depth. Koolen et al. (2) found a good relation between predicted and measured pressure at 30 cm by assuming elastic soil behavior, a principal stress twice as large as the tire pressure, and a $\nu = 4$ (indicative of a normal soil).

The mechanism of soil response to mechanical stress is critically needed to make the link between traffic/tillage and soil properties after the field operation (5). Some (6,7) have measured soil properties after traffic/tillage to evaluate the soil stress-strain process that occurred. Larson and associates (8,9) demonstrated that pore-water pressure measured during a uniaxial stress applied to a bed of aggregates provided a mechanistic explanation of soil strain in highly structured soils. Interactions between interaggregate and intraaggregate pores were emphasized. Our objective was to confirm and extend these explanations of soil strain for the topsoil-subsoil pair in several fine-textured soils of the northern Corn Belt, USA.

MATERIALS AND METHODS

Procedures used were the same as those published (8,9), except that a more sensitive machine was used to apply the stress and measure the strain. Air-dry aggregates (< 2 mm and > 0.5 mm) were sampled from the Ap layer (0 to 25 cm) and adjacent subsoil (25 to 50 cm) of two test soils (Table 1) in midsummer; wheel packed interrows were avoided. These air-dried aggregates were mist wetted to an equivalent matric potential (ψ) $>$-1 kPa and incubated for 2 to 12 weeks at 4°C. Subsamples of 60 g were removed periodically to make a uniaxial stress test (using a universal testing machine) and measure water content (θ_i; g/kg); slow evaporation provided the range of initial water contents (θ_i, g/kg). The desired stress was applied at $<$17 μm/s and held constant within 10^{-4} kPa until stress-strain equilibrated before the next stress was applied. Stress (σ), strain (ρ), and pore water pressure (U_w,8) were measured. The model used was increasing ρ as σ was increased (Figure 1); the linear portion was the virgin compression line (VCL) and the nonlinear segment at low σ was the secondary compression line (SCL). A statistical fitting routine was used to detect the intersection as the locus of points showing greatest curvature. The compression index (C) along the VCL was defined as $\rho = a + C \log \sigma$. The pore water pressure (U_w) decreased as σ increased until a minimum (U_m) was reached, and then increased to zero as σ increased (Figure 2). Usually 10 to 12 loading cycles were needed to define U_m.

Table 1. Particle size, organic matter content, and consistence properties of test soils.

		Particle size			Organic	Consistence parameters[2]		
Soil type[1]	Depth	Sand	Silt	Clay	matter	LPL	UPL	S_{SR}
	(cm)	-----------------	-----------------	-----------------	(g/kg)	-----------------	-----------------	-----------------
Ves	0-25	403	302	396	36.2	224	423	646
clay loam	25-40	399	294	307	30.6	216	422	637
Webster	0-25	348	326	326	47.4	253	444	697
clay loam	25-40	320	342	338	33.0	234	428	662
Standard error		6	3	5	3			

[1]Ves clay loam is a Udic Haplustoll and Webster clay loam is a Typic Haplaquoll. [2]Computed from McBride and Bober (10) and McBride (11); S_{SR} is remolded degree of water saturation.

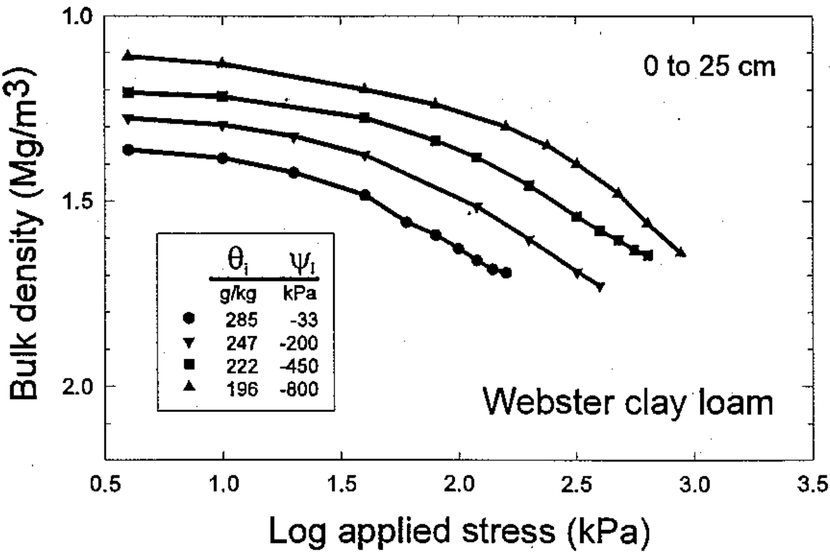

Figure 1. Uniaxial stress-strain relations observed in a bed of <2 mm aggregates from the 0 to 25 cm layer of Webster clay loam (θ_i are the four initial water contents and ψ_i is the matric potential).

Bulk and aggregate densities were field measured to verify loss of interaggregate pore space at U_m, and to test the predicted σ *vs* ρ response at different initial water contents (θ_i).

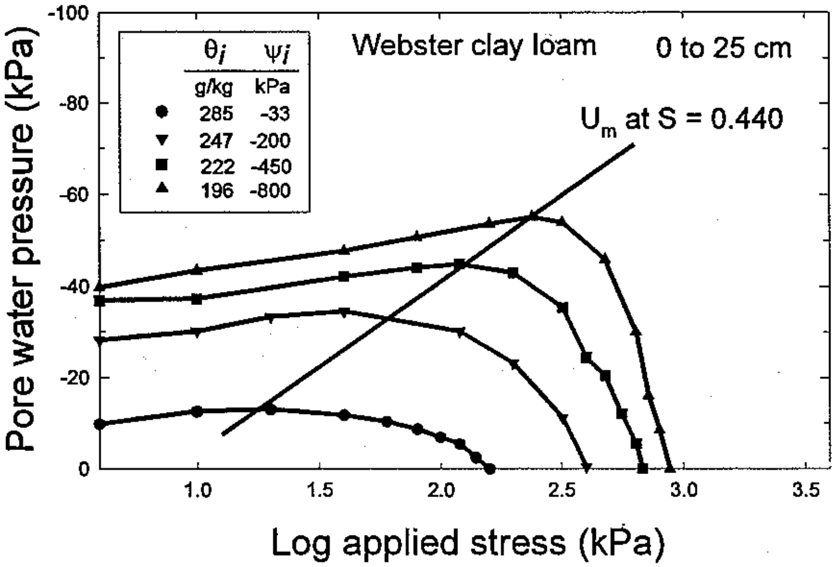

Figure 2. Pore water pressure response during stress applied to a bed of <2 mm aggregates from the 0 to 25 cm layer of Webster clay loam (θ_i are the four initial water contents and ψ_i is the matric potential).

RESULTS AND DISCUSSION

Stress-strain response

The stress-strain curves (Figure 1) for Webster clay loam (0 to 25-cm layer) are similar to those observed for the three remaining test soil layers. Each plotted point has a standard error of $\pm$ 0.02 Mg/m³. The VCL of all four stress-strain curves (one curve for each of four θ_i) can be summarized by the following equation (8):

$$\rho_j = [\rho_k + \Delta_T(S_j - S_k)] + C \log(\sigma_j/\sigma_k) \qquad [1]$$

where ρ_j = test bulk density, ρ_k = bulk density at reference degree of water saturation (S_k) and reference applied stress (σ_k), Δ_T = slope of ρ_k *vs* degree of water saturation (S), S_j =test degree of water saturation, σ_j = test applied stress, and C = compression index. These parameters (Table 2) agree with earlier studies (8,12).

Table 2. Compression index, and parameters (ρ_k, Δ_T, S_k) at 100 kPa reference applied stress[1].

Soil type	Depth	C	ρ_k	$10^4\ \Delta_T$	S_k
			(Mg/m³)		
Ves clay loam	0-25	0.49	1 .42	61	0.66
	25-40	0.53	1.44	45	0.72
Webster clay loam	0-25	0 .32	1.44	480	0.81
	25-40	0.41	1.37	59	0.72
Standard error		0.02		7	

[1]See Eq. [1] for definition of the compression index (C) and the other parameters.

The C values (Table 2) indicate that the Ves soil is less tolerant of stress than the Webster soil; the Ves soil had less clay, more sand, and less organic matter. The increased C agrees with Angers (12) in that C increases as organic matter decreases when the soil contains 350 g/kg clay, and with findings (13) that coarse particles increase C. When fragmented, both subsoils tolerate less stress than their counterpart Ap layer (Table 2); the subsoils have a significant reduction of organic matter and only a small increase of clay compared to their counterpart Ap layer. Increases in C were noted (8,12) as clay increased up to the 330 to 350 g/kg range, and increased organic matter markedly reduces C at clay contents above 350 g/kg (12).

Pore-water pressure response to applied stress

Pore water pressure response to stress applied to a bed of aggregates from the Webster clay loam (0 to 25 cm) in Figure 2 is characteristic of the shapes explained earlier (9). Each plotted point has a std. error of ± 2 kPa. U_w decreases as applied stress (σ_a) increases until $U_w = U_m$. During this phase more contacts are being made between aggregates, but ultimately the interaggregate pores are small enough for menisci to coalesce. Pores are then filled with water from within the aggregates--pore water pressure then decreases more abruptly (9). Some shear must occur at the contact points between aggregates (14). At the point when $U_w = U_m$ then $\sigma_a = \sigma_c$ (critical stress) because as σ_a is increased the interior of the aggregates undergo shear as they approach saturation. Figure 2 shows that U_w has a lower value as θ_i decreases because smaller pores are needed for menisci to coalesce--U_m is lower and occurs at a higher σ_a. U_w was lower in the Ap than in subsoil layers at the same σ_a (i.e. smaller pores must be produced to coalesce menisci formed in the interaggregate spaces). Koolen and Kuipers (15) cite several mechanisms to support these explanations (9) for U_m coincident with occluded interaggregate space.

Significance of minimum pore water pressure

A normalization procedure (9) was used to estimate U_m and σ_c (see line through lowest U_w in Figure 2). It was found (9) that S_m (water saturation at U_m) is a constant for a given soil independent of θ_i, and lies midway within the plastic range of soil consistence defined by the water saturation at LPL and UPL (Table 3). A constant ρ_c for a soil independent of θ_i was observed. Applied stress beyond that at U_m is assumed to deteriorate soil structure. With this approach one can use the θ_i - σ_c - ρ_c linkage to apply these uniaxial stress relations in the field. Finally U_m occurred at a higher ρ_c in the Ap layer.

Table 3. Constants (ρ_c and S_m) at U_m independent of θ_i and the estimated water saturation at the consistence limits[1].

Soil type	Depth	ρ_c	S_m	S at consistence limits LPL	UPL
	(cm)	(Mg/m³)			
Ves clay loam	0-25	1.46	0.50	0.35	0.66
	25-40	1.38	0.48	0.34	0.66
Webster clay loam	0-25	1.382	0.44	0.36	0.64
	25-40	1.28	0.48	0.35	0.55
Standard error		0.02		7	

[1]ρ_c is critical stress at U_m the minimum pore water pressure; S is water saturation; S_m is water saturation at U_m, LPL is lower plastic limit; and UPL is upper plastic limit.

For a given soil, U_m ranged from the intersection of the SCL and the VCL to points on the VCL depending on θ_i. For each U_m, there was a ρ_c - σ_c pair to locate where the U_m would occur on a stress-strain relation in Figure 1; because ρ_c was a constant for a given soil at U_m, σ_c changed as θ_i was changed. Another pair, ρ_x - σ_x, was defined at the intersection of the SCL and the VCL (Figure 1). At the highest θ_i, U_m occurred near the SCL and the VCL intersection, and as θ_i decreased U_m occurred at higher σ_a (data not shown). Assuming that soil structure is deteriorated when $\sigma_a > \sigma_c$, these measurements illustrate the mechanism for potential damage when the soil was stressed at θ_i above the LPL; the stresses involved are about 20 kPa (Figure 1).

Ancillary measurements of aggregate density supported the contention that U_m occurs at the collapse of interaggregate porosity. Measured density of dry aggregates in the Ap layer, COLE values of shrinkage *vs* water content, and a $\psi(\theta)$ characteristic were all used to estimate aggregate density as a function of θ. Then the interaggregate porosity at U_m was estimated as a function of aggregate density and ρ_c. Average estimated interaggregate porosities were 0.007 and 0.062 m³/m³ for the Ves and Webster soils, respectively at U_m.

CONCLUSIONS

Compression characteristics for Ap-subsoil counterparts in several clay loams confirm that the compression index is sensitive to soil contents of clay, organic matter, and sand. The Ap vs subsoil comparison demonstrated that soil organic matter increases tolerance to stress. Pore water pressure responses during stress reaffirm the value of minimum pore water pressure and the associated constant water saturation (within the plastic consistency) for a given soil. The constant bulk density at the minimum pore water pressure observed in our study provides the triple relation of critical stress-constant bulk density-initial water content, that can be used to explain the manner of soil-compaction sensitivity to soil water content at time of field operations. Further evaluation is needed to explain why strain per unit stress in the field exceeds that in the uniaxial test.

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EFFECTS OF UNIAXIAL STRESS ON THE DEGREE OF COMPACTNESS IN FOUR SOILS

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ABSTRACT

The objectives of this work were to investigate the effect of compactive stress on soil degree of compactness and to evaluate the resultant soil physical properties. Various stresses (25, 50, 100, 200 and 400 kPa) were applied on disturbed soil samples. Maximum dgegree of compactness (D) in loamy sand was obtained in the driest (1g $100g^{-1}$) sample. In clayey soils, samples drier than 20% mass wetness were not tested and maximum D was reached when the soils were compressed at or slightly below field capacity. However, the soil wetness at which maximum D was obtained decreased with the increase of compactive stress. In wet clayey soils, soil moisture tension varied with D as affected by stress. Soil moisture may to affect induced soil compaction differently depending on the manner by which the wetness (drying or wetting) is obtained.

INTRODUCTION

Compaction of agricultural soils is one of the main causes of soil degradation, which has drawn the attention of agricultural scientists and farmers. In minimizing the problems caused by soil compaction, it is necessary to conduct a detailed study of the compaction process and the resultant soil physical conditions. However, such studies in the field are not always feasible due to economical and technical reasons. On the other hand, laboratory experiments can not fully represent the complex field conditions. But field and laboratory tests together can give us a comprehensive view of the causes and effects of soil compaction.

The effects of applied stress and soil wetness at compaction on bulk volume have been investigated in the laboratory by various researchers (see for example 1 and 2). The results elucidated the relationship between the compactive stress and soil bulk density. However, due to inherent soil variations, transfer of research results from one soil to another is not always feasible.

The purposes of this work were to study the degree of compactness, D, (3) as a function of applied stress on four Swedish arable soils at various moisture levels, and to determine the effect of the resultant D on other soil physical properties.

MATERIALS AND METHODS

A compaction experiment was carried out on four Swedish agricultural soils. The soils were sampled from mouldboard ploughed fields, which had been treated with conventional agricultural machinery and practices for many years. The samples were stored for a period to allow some drying, and disturbed to pass a mesh with 25-mm width, and stones > 25 mm were removed. The sieved soils were moistened to various wetness, stored under a polyethylene plastic cover and regularly mixed for a minimum of one week for moisture equilibration.

Two tensiometers (2100F Soil Moisture Probe) were used to monitor the matric tension of individual soil samples. If drying was necessary the plastic cover was removed and the soil was mixed every 30 minutes until the desired tension was attained. Conversely, if moistening was needed water was sprinkled. Table 1 depicts the parcticle size distribution, organic matter content, particle and reference bulk densities. Reference bulk density is described below. Soil particle-size analysis was carried out with the pipette method. Organic matter content was determined by combustion. For textural classification the International Society of Soil Science (ISSS) system was used (4).

Soil compaction was carried out using an equipment for uniaxial stress (3) in an undrained mode. Approximately 12 litres of disturbed, loose soil were placed in a metal bin with a 35 cm inner diameter and 14 cm height. Prior to compaction, two tensiometers mentiond earlier were installed in each bin at 2 cm above its base to monitor soil tension. Then, various stresses (25, 50, 100, 200 and 400 kPa) were applied to the soil sample in increasing order. Each stress was applied for 20 seconds and after that the sample was left unloaded for 24 hours to allow water redistribution and soil rebound. Afterwards the height and tension of the sample were recorded. Initial and final height of soil sample were approximately 12 and 6 cm, respectively. After the last loading, the sample was oven-dried and weighed to determine dry bulk density. The experiment was replicated twice for each soil and water content.

The degree of compactness, D, was calculated as a ratio between the treatment bulk density and a reference bulk density, multiplied by 100. The latter was determined on the same soil type by a standardized uniaxial test (2 replicates per soil) with a static pressure of 200 kPa (3). The consolidation started with wet soil sample allowed to drain for a week under the static stress. D at 90 and 100% water saturation was estimated from the volume relationship of soil solid, liquid and air phases.

Table 1. Particle size distribution and organic matter content (g kg^{-1}), and reference bulk density

Location	Texture	Particle size ranges (µm) < 2	2-20	20-2000	Organic matter	Particle density	Reference bulk density ($Mg\ m^{-3}$)
Säby	light clay	300	195	505	37	2.61	1.54
Ultuna	heavy clay	496	315	189	21	2.66	1.53
Ekenäs	humus-rich clay	484	405	111	227	2.23	0.83
Ultuna	loamy sand	60	42	898	19	2.63	1.52

RESULTS

The effect of the applied stress on the degree of compactness (D) is illustrated in Figs. 1a-1d. There was a linear relationship between D and the log of applied stress over a limited range, which was widest for loamy sand. Figs 2a-d show the relationship between D and mass wetness at compaction. In general, D first increased and then decreased with the wetness. However, in the loamy sand maximum D was obtained at the lowest mass wetness (1%). The minimum D for this soil was obtained when compression occurred at about 8% wetness,

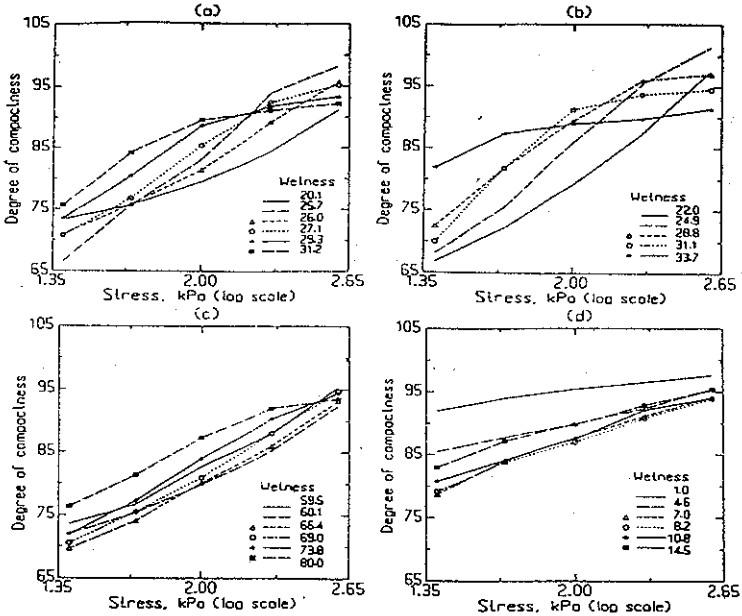

Fig.1. Degree of compactness (D) as a function of applied stress:(a) light clay , (b) heavy clay, (c) humus-rich clay and (d) loamy sand.

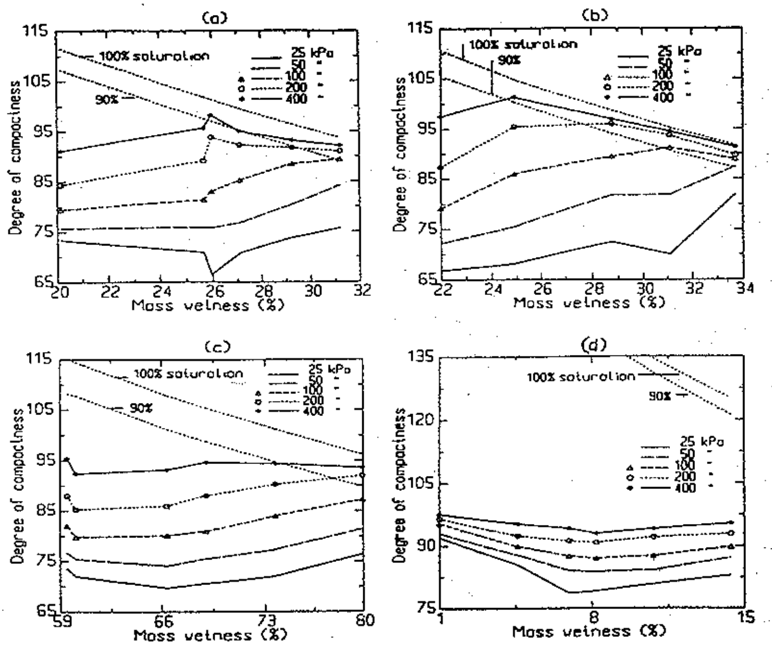

Fig.2. Degree of compactness (D) as influenced by soil water content at the time of compaction: (a) light clay, (b) heavy clay, (c) humus-rich clay and (d) loamy sand.

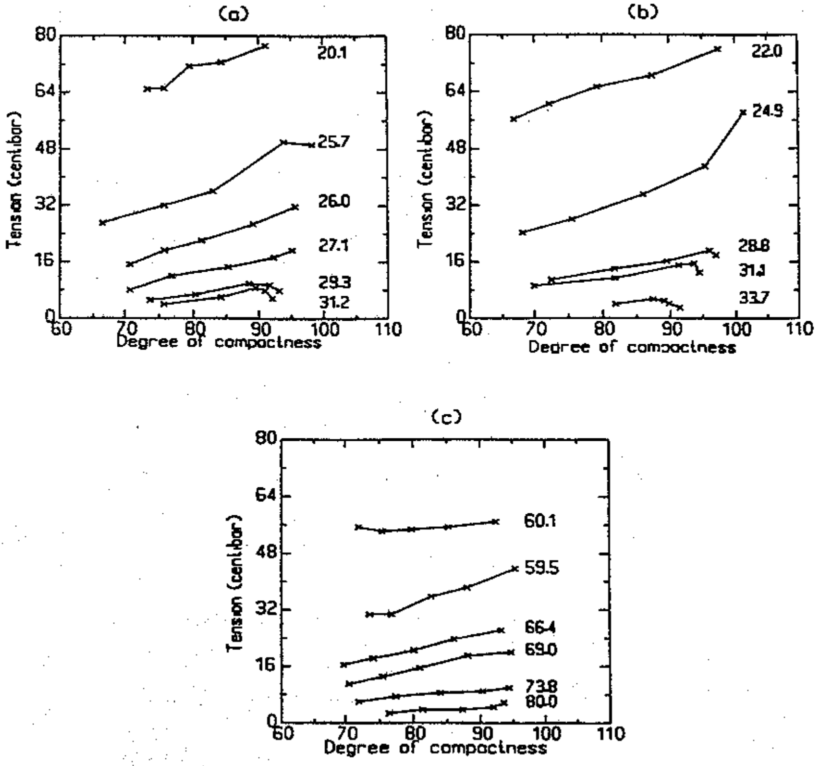

Fig.3. Soil water tension as affected by Degree of compactness (D): (a) light clay, (b) heavy clay and (c) humus-rich clay.

beyond which D increased again. Figs. 3a-c illustrates change of soil water tension with D in clayesy soils. No markable change of tension with D was observed in loamy sand. Soil water retention, air permeability and hydrualic conductivity measurement results will not be presented here.

DISCUSSION

The log of applied stress and the resultant bulk density were linearly related over some of the applied stress and water content at compression. This is in agreement with earlier findings (1 and 2). The log-linearity occurred from about 50 kPa. As moisture content increased the difference between D obtained with various stresses diminished, indicating the importance of adapting the stress to the wetness to avoid soil overcompaction. The fall of D after its maximum was attributed to the high degree of saturation resulting in very low air-filled porosity. In this confined soil sample, no loss of water occurred during compaction. This type of phenomenon may be encountered in the fields. However, during field traffic on wet soils the exerted stress displaces the soil including the water sidewards. In effect, the soil under the central part of the tyres may receive more stress. Thus, the same average stress is expected to produce greater maximum D under field traffic than in laboratory-compacted soil. O'Sullivan (2) found that higher stress was needed in the laboratory tests than in the field to produce a similar void ratio.

Maximum D was obtained at or slightly below field capacity (1 m suction) for clayey soils. It increased with stress, implying that higher mean ground pressure can cause soil overcompaction even at lower wetness.

The increment in D as affected by stress seems to increase with clay content, and decrease with increased organic matter for the clayey soils. This is in agreement with previous findings (1). The humus-rich clay had relatively greater total porosity than other soils irrespective of applied stress and wetness and was at least 64%. However, this does not exclude aeration problems in such soils. As organic soils are often found in wet area and their water holding capacity is very high air-filled porosity can drastically drop causing aeration deficiency. For instance, when the wettest sample was compacted with 400 kPa the total porosity was 65% but the air-filled porosity was only 2.6%. Furthermore, there may be a high oxygen consumption in the soil caused by high microbial activity.

The log-linear relationship between D and applied pressure in loamy sand for all wetness is due to the fact that there was sufficient air-filled porosity in the sample, which means that further compression is possible. The minimum air-filled porosity which was obtained at the greatest mass wetness (14.4%) and stress (400 kPa) was 23.8%. This implies that the constraint for crop establishment encountered in compacted sandy soils is mainly associated with mechanical impedance to root growth rather than limited aeration.

High yield of most cereals is obtained at a D-value of about 87 (Håkansson et al., 1988). In light and heavy clay soils, maximum D was around this optimum when 50 kPa stress was applied to the wettest samples. Although the loading time (20 s) was much longer than at normal field traffic, the same mean ground contact pressure, especially at several passes, can produce higher D in field situations implying the proneness of wet soils to compaction even at pressure as low as 50 kPa.

Soil texture directly influences soil compaction through its particle geometry. For instance, Bodman and Constatin (5) found that the maximum bulk density occurred in a loamy sand. In our experiment, the loamy sand with about 90% sand fraction (20-200 µm) was more compacted than clayey soils but only in the stresses of 100 kPa or less. This might be attributed to the finer particles which filled the voids between the coarser sand grains.

A decrease of larger pores as affected by stress could have caused the more pronounced effect of D on soil water tension in light and heavy clay soils. The humus-rich clay showed similar trend as the other clay soils but with less increment of tension per unit increase of D, indicating the positive effect of organic matter content in reducing the hazardous effects of soil compaction. By contrast, the tension of the loamy sand was unaffected by D, implying that in single-grained soils the water capacity (mass wetness) is almost independent of D.

Various natural factors such as wetting and drying cycles act on a soil and often modify its physico-mechanical properties. Clay soils are much affected by these factors. In this work the D-values obtained 24 hours after were compared. This makes it uncertain to relate the results to conditions prevailing in the field. For instance, if drier clays were compacted, rewetted and allowed to swell their D-values would have been lower than the results presented here. However, the changes in D would have been minimal if samples were compacted at greater wetness. So far, however, it has not been possible to more closely consider the consequences of the swelling/shrinking processes.

Finally, it is not merely the wetness at compaction which influences D but also the process by which this wetness was obtained. Although their mass wetness was almost equal (25.7 and 26.0 g/100g dry soil) two samples of the light clay resulted in different D-values after compression with various stresses. This might be attributed to the manner (i.e., by wetting or drying) by which the final wetness was obtained.

CONCLUSION

In general, D increased with stress and wetness but maximum D in the loamy sand was attained in dry samples irrespective of applied stress. When the clayey soils were compacted by high stress in wet condition, maximum D was reached at or below field capacity (1 m suction). In wet clayey soils, soil moisture tension varied with D as affected by stress.

Air-filled porosity was greatest in the loamy sand regardless of stress and water content. This indicates the negative effect of mechanical impedance rather than aeration deficiency on crop establishment in sandy soils. Air-filled porosity was higher in humus-rich clay than in the other two clayey soils, suggesting the positive effect of high organic matter content on soil physical properties. The influence of soil moisture on induced soil compaction was more prononced at lower compactive stress indicating the importance of choossing the right compactive stress adapted to the prevailing soil moisture in order to achieve moderate recompaction.

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A STATISTICAL MODEL FOR PREDICTING SOIL COMPACTION BASED ON MATRIC SUCTION

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ABSTRACT

Undisturbed soil cores (taken from two contrasting Entisols, an Alfisol and a Vertisol) were compressed by static loading up to 300 kPa, at two rates of straining (0.38 and 1.52 mm min^{-1}, respectively). Before loading, the samples were equilibrated at a series of matric suctions, namely 0, 1, 10, 100, 10^3 and 10^5 kPa. The stress, S, versus deformation (decrease of samples height), D, curves obtained for all soils, straining rates and matric suctions studied were of the form D = a + C lnS. Curves, determined for each soil at different matric suction, were approximately parallel to each other over the whole range of water tensions and shifted downwards as water suction increased. If the stress - deformation curve of a soil at one matric suction (T_k) is known, a procedure is suggested to predict any stress-deformation curve for the same soil at any other matric suction (T_i) by the following relationship $D_i = a + a_1 \ln(T_i / T_k) + C \ln S$, where a_1 is the slope of the curve deformation (at a given stress) versus matric suction.

INTRODUCTION

Although conservation tillage systems have been introduced in many parts of the world, compaction of agricultural soils is still a problem of a worldwide concern, because of the continuous development and use of heavier agricultural machinery and the intensification of agricultural practices. Compaction influences most of the properties and processes taking place in soils. These include bulk density, porosity and pore size and continuity and consequently water content, rates of conduction of water, gas and heat as well as penetration resistance. The factors affecting soil susceptibility to compaction include stability of structure, particle size distribution, particles' characteristics, such as roundness, sphericity and surface roughness, stress applied and duration of loading (1,3,4) while the role of moisture content seems to be very important (2). At any moisture content and due to the presence of air-water and solid-water interfaces and the consequent attractive forces, the soil particles are held in place and are not "free" enough to be rearranged during compression, unless the stress applied is greater than these attractive forces. At low moisture content, the forces of interaction between the solid and liquid phase (matric suction) increase and the soil is less susceptible to compaction under loading. Therefore, compressive stress and matric suction are having opposing effects on compaction and hence both of them have to be taken into account in compaction studies. Despite of this common knowledge no much work has be done so far on the effect of matric suction on the compaction of field soils. The objectives of this work were: i) to study the relation between applied stress and compaction at different matric suctions and ii) to derive a general relationship for calculating soil compaction, if matric suction is known.

MATERIALS AND METHODS

From four soils (two Entisols, an Alfisol and a Vertisol), representative of agricultural soils of Greece and of varying basic properties (Table 1), undisturbed samples were taken by means of stainless steel cylinders (57 mm in diameter and 40 mm in length). The cores were water saturated under vacuum (2-3 kPa) and allowed to equilibrate at a series of matric suctions namely, 0, 1, 10, 100, 1000 and 10^5 kPa. After equilibration, the cores were stressed uniaxially and continuously from zero to 300 kPa, by static loading. A compression test machine (Wykehame Farrance Eng. Ltd) was used for the experiments, and two rates of straining were applied (0.38 and 1.51 mm min^{-1}, respectively). The range of stresses applied was chosen to cover the stresses applied to field soils by agricultural machinery. Porous ceramic plates were put at the top and the bottom of the cores before stressing. During the compression tests, both the load applied and the deformation (decrease of the sample length) were recorded, and more than ten load-deformation values were taken for each test. The stress applied was calculated as the load divided by the area of the sample base while the deformation values recorded were converted to % deformation on an initial sample length basis. Three replicates were used for each soil, strain rate and matric suction studied.

RESULTS AND DISCUSSION

From Table 1 it appears that the soils used differ in particle size distribution, aggregate size and stability as well as in linear shrinkage.

Table 1. Selected chemical and physical properties of the soils

Property / Soil	Entisol-1	Entisol-2	Alfisol	Vertisol
pH	7.70	5.90	7.25	7.5
organic matter, g kg^{-1}	25.5	15.7	11.7	24.0
E.C., dS m^{-1}	2.15	1.04	1.55	0.53
$CaCO_3$, g kg^{-1}	25.9	2.2	5.7	7.0
C.E.C., mmol (+) kg^{-1}	329	105	203	-
sand (2000-50 μm), g kg^{-1}	79	716	566	221
silt (50-2 μm), g kg^{-1}	442	220	136	278
clay (< 2 μm), g kg^{-1}	479	64	298	501
bulk density (at saturation), Mg m^{-3}	0.80	1.47	1.32	1.11
mean weight aggr. size, mm	2.70	0.94	2.56	3.24
aggregate stability, %	75	37	90	65
linear shrinkage, %	8.9	0	9.0	20.2

The results of compactive stress versus % deformation (settlement), for any soil, matric suction and strain rate applied, were always best fitted to a simple equation of the form

$$D = a + C \ln S \qquad (1)$$

where D stands for % deformation and S is the stress applied. Typical examples of this agreement are illustrated in Fig. 1, while in Fig. 2 the stress-% deformation curves of Entisol-1 for all matric suctions applied are presented. From Fig. 2 and the corresponding curves for the rest of the soils (figures not given), it was evident that: a) the slope of the stress- % deformation curves is very steep at the beginning of stressing and decreases progressively with increasing stress, b) the curves are linear over the applied stress from about 50-100 kPa (depending on soil, rate of straining and matric suction) up to 300 kPa and c) the linear parts of the curves are displaced downward as the matric suction increases, and are approximately parallel to each other. The shifting of the stress vs deformation curves justifies that matric suction plays a significant role in soil compaction, i.e., for a given stress applied, any increase in matric suction results in a decrease of deformation. This is attributed to the increasing attractive forces acting between particles and the consequent greater resistance of particles to rotation, movement and rearrangement during loading.

The slope of the stress - % deformation curves (the term C in Eq. (1)) was found to increase in the order Entisol-2, Alfisol, Entisol-1, Vertisol and significant differences were obtained between soils. The change of C between soils had the same trend as

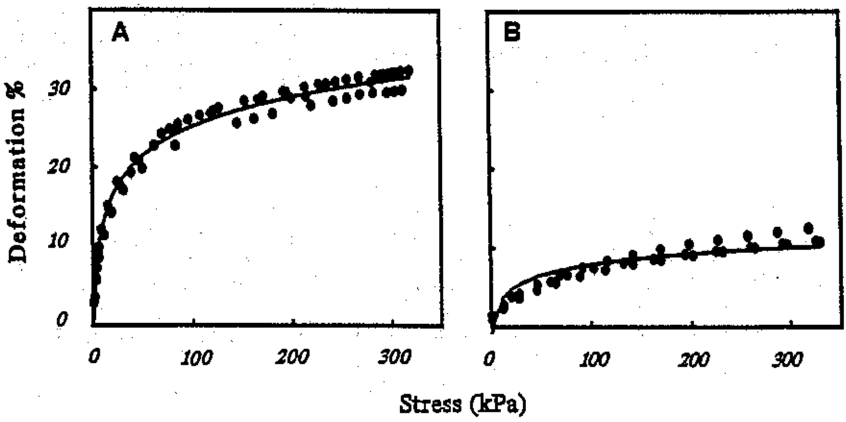

Fig. 1. Stress-% deformation measured values and the curves predicted by Eq. (1). (A) Entisol-1 equilibrated at 1 kPa matric suction and compressed at a strain rate of 0.38 mm min^{-1}. (B) Entisol-2 equilibrated at 1000 kPa matric suction and compressed at a strain rate of 1.52 mm min^{-1}.

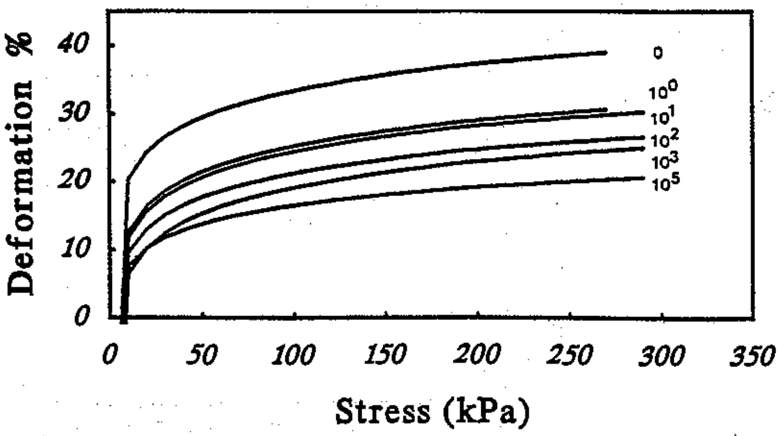

Fig. 2. Stress-% deformation curves of Entisol-1 compressed at a strain rate of 0.38 mm min^{-1}. The numbers next to the curves express matric suction (kPa).

clay content (Table 1) and a close relation ($R^2 = 0.95$, $p<0.05$) was found between C and clay content. These results are in agreement with those of Larson et al. (2) who also suggested a close relationship between compression index and clay content. No significant differences in C were found between the two rates of straining studied. A trend of decreasing C with increasing matric suction was observed and the slope, C, of the samples equilibrated at 1000 and 10^5 kPa matric suction, was significantly less than the corresponding values of samples equilibrated at smaller matric suctions.

It was found that the % deformation, at a given constant stress, corresponding to the turning point of each curve or very close to it, varied linearly with the logarithm of matric suction and that the relationships, for any single soil and rate of straining, were very close. The values of R^2 ranged from 0.90 to 0.99, with most values being >0.95. The close relationships found between deformation at constant stress and matric suction along with the parallel order of the curves of each soil, mentioned above, allows someone to calculate the deformation, D_i at any matric suction, T_i , from the following relationship

$$D_i = a + a_1 \ln(T_i / T_k) + C \ln S \qquad (2)$$

if Eq. (1) is known for a matric suction T_k and where a_1 is the slope of the curve % deformation (at a given stress) versus matric suction. The procedure for the derivation of Eq. (2) was similar in principle to that suggested by Larson et al. (2) for the prediction of compression curves based on moisture content or on degree of water saturation. The predicted stress vs deformation curves calculated by using Eq. (2) against the measured values for all soils used are given in Figs 3 and 4. These figures

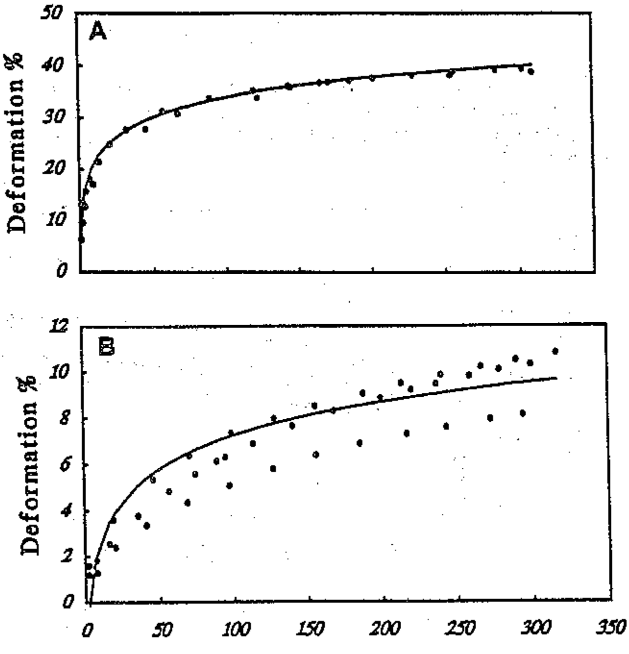

Fig. 3. Calculated [Eq.(2)] stress-% deformation curves as compared with measured values. (A). Entisol-1 equilibrated at 0 kPa matric suction and stressed at a strain rate of 0.38 mm min^{-1}. (B). Entisol-2 equilibrated at 100 kPa matric suction and stressed at a strain rate of 0.38 mm min^{-1}.

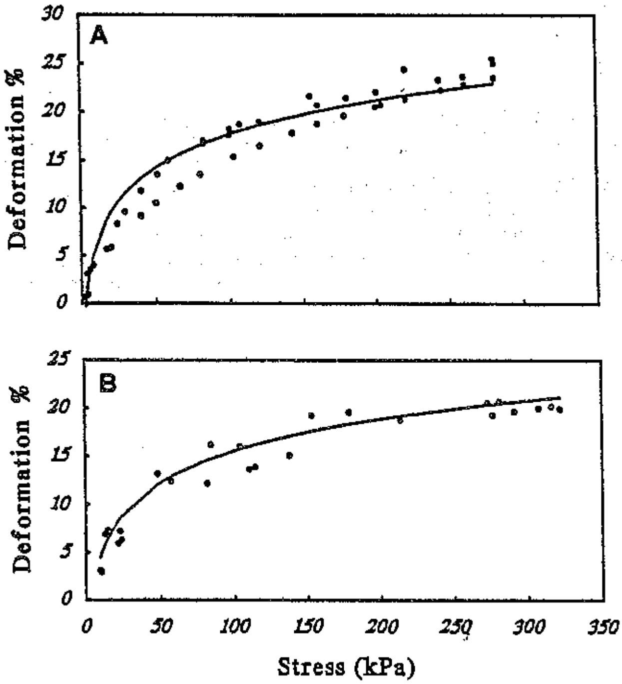

Fig. 4. Calculated [Eq.(2)] stress-% deformation curves as compared with measured values. (A). Alfisol equilibrated at 10 kPa matric suction and stressed at a strain rate of 0.38 mm min^{-1}. (B). Vertisol equilibrated at 1000 kPa matric suction and stressed at a strain rate of 0.38 mm min^{-1}.

illustrate the very close agreement between the measured and computed values in the whole range of stress applied and not only for the linear part of the curves, as the model of Larson et al. (2) can predict.

The less agreement between measured values and the curve calculated from Eq. (2) in Entisol-2 (Fig. 3B) as compared to the other soils used can be attributed mainly to that compaction of sandy soils depends on particles' characteristics (sphericity, roundness, surface roughness) rather than the presence of water (4).

CONCLUSIONS

The main conclusions of this work are summarised as follows:

1) The stress (S) vs deformation (D) curves obtained for all soils, equilibrated at any matric suction before loading and stressed under different rates of loading were of the form D=a+ClnS.

2) The linear parts of the stress-deformation curves were shifted downwards in a parallel order with increasing matric suction.

3) The slopes of the stress-deformation curves were found to be closely related to clay content and influenced by matric suction and

4) A model is suggested for calculating the deformation of a soil, with stress, at any matric suction if the relation between deformation and matric suction (at a given stress) and Eq. (1) at anyone matric suction are known.

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EFFECTS OF LOAD, TYPE OF LOADING AND SOIL WATER CONTENT DURING LOADING ON POROSITY AND AIR-FILLED POROSITY OF A SANDY LOAM TOPSOIL

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ABSTRACT

The effects of uniaxially applied loads in the laboratory and loads applied by a roller in the field at varying soil water content on the porosity and the air-filled porosity at -10 kPa matric water pressure were investigated for a loose sandy loam topsoil from 1988 to 1992.
Both porosities clearly decreased: a) with increasing roller or uniaxial load and b) with increasing soil water content, for uniaxial loading. The water content effect was less for roller loading; here, the water content - porosity curves showed a maximum at certain water content. This difference in effect between the two types of loading can be explained by the 'degree of confinement' of the soil during loading.
Wet loading caused the air-filled porosity at -10 kPa matric water pressure to decrease more than proportional to the porosity. This was caused by an observed increase in water content at -10 kPa matric water pressure (% w/w) with increasing water content during loading, practically independent of the load or type of loading.

INTRODUCTION

Early sowing in spring is a prerequisite for good yields of some important crops in the Netherlands. Seedbed preparation operations are usually carried out on ploughed soil as soon as the top layer is considered dry enough to be tilled. In the Dutch situation, the lower part of the ploughed soil layer, i.e. the root bed, usually remains wet for a long time because of the absence of evapotranspirating vegetation and high ground water tables, causing upward capillary water transport. Under such conditions, wheel traffic may easily cause compaction damage to the root bed. It was hypothesized, that the differences in yield found between a low and a high ground pressure traffic system (1) might originate from traffic in spring under the described conditions. Therefore the effects of soil loading and soil water content in spring on soil condition and crop growth were investigated by field experimentation from 1988-1992. A field traffic simulation technique was used to study the wheel-soil-crop growth relationships with a smaller set of parameters and with fewer sources of variation than in usual field experiments (2). The present report focuses on the effects of load, type of loading and water content during loading on the soil condition obtained. The overall objective of the experiment was to contribute to further development of practical guidelines for traffic on arable land in spring.

MATERIALS AND METHODS

Two types of loading were investigated: uniaxial loading in the laboratory and loading by a steel roller in the field. While the steel roller can be considered to simulate a rigid tyre, the loading of soil at some depth under the soil surface by an ideal (extremely flexible) tyre, without slip, is considered to be best simulated by uniaxial loading. The effects of real tyres is expected to be intermediate between the effects of the roller and uniaxial loading.

Uniaxial loading

Uniaxial compression tests were performed on soil aggregates with a diameter of 2.8 to 4.0 mm, taken from the experimental site where the roller-loadings were investigated. For particulars on the soil, see below. Pressures applied were 100, 200, 400 and 800 kPa on samples with water contents ranging from 14 to 26 (% w/w). The aggregates were compressed in cylinders with an inside diameter of 7.57 cm and a height of 5 cm. The compression speed was 1 mm s^{-1} and the pressure was released as soon as the target pressure was reached. The measurements included total porosity during and after loading and air-filled porosity at -10 kPa matric water potential after loading.

Loading by a steel roller

The experimental site was situated near Slootdorp in the Northwest of the Netherlands. Mean annual rainfall at this location is 810 mm, evenly distributed over the year. The soil is classified as a typic Fluvaquent (3). Typical mineral-particle size distribution of the topsoil is 15% clay, 26% silt and 49 % sand, which classifies as a sandy loam (USDA classification). The topsoil further contained 2% organic matter and 10% $CaCO_3$. A course-sandy layer directly under the topsoil was very hard and assumed to be not further compressible.

In autumn the field was tilled with a rotary digger to a depth of 25 cm. After the application of the loading treatments on soil strips, 2 m wide, in spring, secondary tillage was performed with a rotary harrow to a depth of 3 to 5 cm. Soil loading other than that by the roller in spring was prevented by using a tractor with a track width of 3 m, which straddled the soil strips, for all other field operations. Test crops grown were peas (1988 and 1989), brussels sprouts (1990) and broccoli (1991 and 1992).

The loading treatments were the application of no load (U) and loads of 4.5 Mg (L), 8.5 Mg (M) and 14.5 Mg (H) on a smooth steel roller, 2 m wide and 1.2 m in diameter, at a forward speed of 1 m s^{-1}. By exception, H was the application of 16.5 Mg on the roller in 1988. To avoid excessive bulldozing effects, M was preceded by L, and H was preceded by L and M. The time between pre-loading and the main treatment was less than two hours. The experimental field was divided into three blocks. Within each block, the loading treatments were randomly assigned to one of four soil strips, 3 m wide and 83 m long, giving a total of 12 soil strips. This lay-out was maintained for the loading treatments during the five experimental years.

The field lay-out for moisture treatments varied in the years of the experiment. In 1988 and 1989 each soil strip was divided into three equal plots, giving a total of 36 plots. Two out of three plots were differently irrigated in late spring to vary the water content between plots during the traffic event. In 1990 the water content during traffic was varied by applying the loads to each block on a different date. In 1991 and 1992 the water content was not varied intentionally and measurements were done on one plot per soil strip.

For the L-, M- and H- loadings, the loading was assumed to be similar at all depths in the topsoil due to the hard subsoil layer and the large size of the roller. It was also assumed that the soil porosity before loading was similar for these three loadings each year. Thus, each combination of loading treatment and soil water content during traffic, averaged per plot, was analyzed as being an independent measurement, irrespective of year and date of measurement and sampling depth. For the U-plots, the soil condition was assumed to be mainly determined

by the load of the overlaying soil in winter.
The soil water content at 10 and 20 cm depth, just before loading, was determined from 10 auger samplings. In 1988 this was done per group of plots that received the same irrigation treatment. In other years, the water content was determined on each plot. After loading, porosity and air-filled porosity at -10 kPa matric water pressure were determined on 100 cc soil samples, taken at depths (d) of 10 cm (7.5-12.5 cm) and 20 cm (17.5-22.5 cm).

RESULTS AND DISCUSSION

Uniaxial loading

The measured porosities and air-filled porosities for uniaxial loading are presented in Figures 1 and 2 for varying uniaxial stress and water content during loading (m_d). Figure 1 shows the porosity during loading at target stress (ϕ_{unrec}) and the porosity 15 minutes after loading, when the soil is mostly recovered (ϕ_{rec}). Both an increase in uniaxial stress and in m_d resulted in decreasing porosities. The relationships with the porosities are approximately logarithmic for uniaxial stress and linear for m_d, down to the point where the soil was almost saturated during loading.

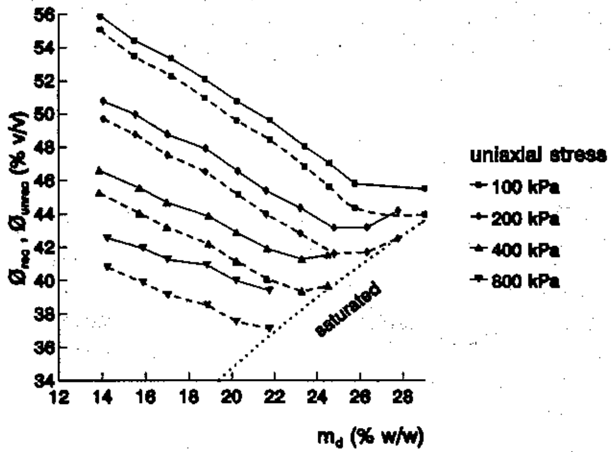

Fig. 1 Porosity during uniaxial loading at target stress (ϕ_{unrec}, dashed line) and porosity 15 minutes after loading (ϕ_{rec}, solid line) as a function of the soil water content during loading (m_d) and uniaxial stress.

Figure 2 shows the air-filled porosity 15 minutes after loading ($\phi_{a,\ rec}$) and after adjustment to a matric water pressure (p_m) of -10 kPa ($\phi_{a,\ -10}$). The last property is important for evaluation of the suitability of the soil for plant growth (4,5). The value of $\phi_{a,\ rec}$ shows a similar type of relationship with uniaxial stress and m_d as was found for the porosities. However, for $\phi_{a,\ -10}$, the relationship with m_d is clearly not linear. The curved nature of the line for $\phi_{a,\ -10}$ can be fully explained by the replacement of air by water due to an increase in water content at p_m = -10 kPa (m_{-10}, in % w/w) when m_d increases (Fig. 3). The change in m_{-10} depends very much on m_d and only little on the stress applied. The relationship between m_d and m_{-10} has been previously observed after uniaxial compression at 400 kPa (6). The feature of increasing m_{-10} when the soil is manipulated at high water contents is associated with changes in the micro-structure of the soil (pores $< 30\ \mu m$). It is

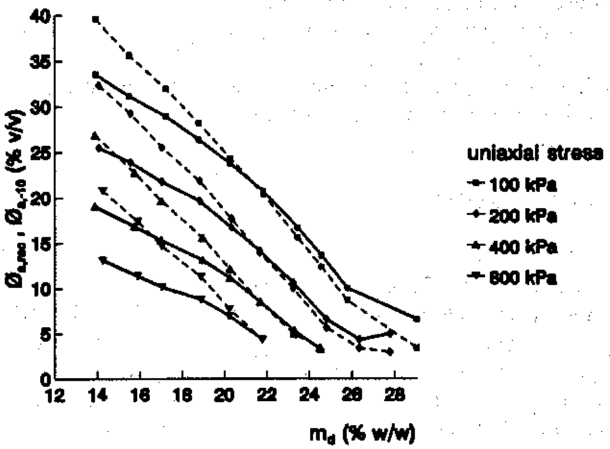

Fig. 2 Air-filled porosity 15 minutes after uniaxial loading ($\phi_{a,\ rec}$, dotted line) and after adjustment to p_m = -10 kPa ($\phi_{a,\ -10}$, solid line) as a function of the soil water content during loading (m_d) and uniaxial stress.

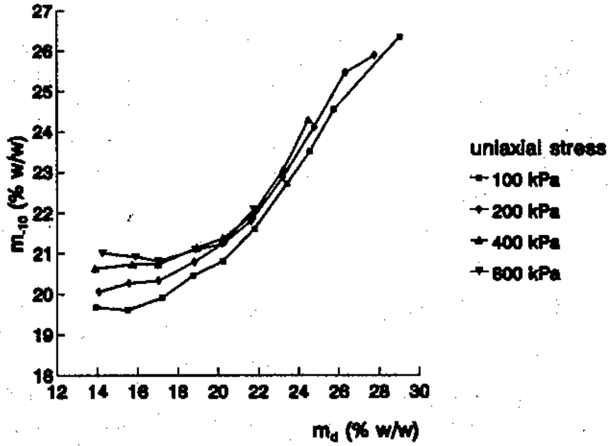

Fig. 3 Soil water content at p_m = -10 kPa (m_{-10}) as a function of the soil water content during loading (m_d) and uniaxial stress.

hereby suggested that this increase in m_{-10} might partly disappear after some time, due to the rearrangement of soil particles. Soil properties on a micro-scale ,after loading, are known to change in time. For instance, an increase in soil strength after subjecting wet compacted soil to a drying and wetting cycle was found (7).

Loading by a steel roller

The resulting porosity after application of the loading treatments with varying soil water content in the field is presented in Figure 4.

The U-treatment resulted in high porosities, per definition independent of the water content during loading of the other plots. The porosity (ϕ) on U-plots at 20 cm depth was about

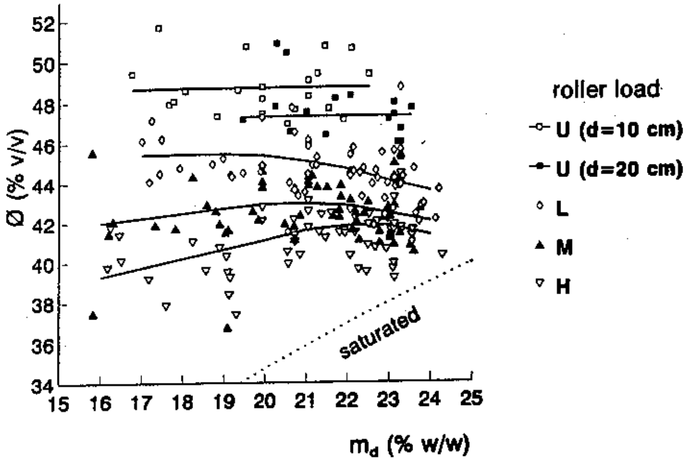

Fig. 4 Porosity after loading by the roller (ϕ) as a function of the soil water content during loading (m_d) for each loading treatment.

1.5% lower than at 10 cm depth, reflecting the effect of stress exerted by overlaying soil, which is estimated to be 17 kPa at 10 cm depth and 35 kPa at 20 cm depth.

Loading the soil by the roller resulted clearly in a decreasing ϕ with increasing load. The effect of the water content during loading (m_d) differed for the loading treatments L, M and H. With m_d increasing up to about 22%, ϕ decreased for L, but increased for H. The effect of m_d on ϕ for M was intermediate between those of L and H. It is suggested that three effects are responsible for this behaviour:

1) Soil strength decreases with increasing water content, resulting in less resistance to compaction.
2) Likewise the resistance to deformation and flow decreases with increasing m_d.
3) The lowest obtainable porosity increases when the water content increases and, thus, saturation occurs at higher porosities.

Effect 1 predominates in the case of low loading (L). Very likely, effect 2 caused the actual peak stresses under the roller to be much higher in dry than in wet soil. An explanation for this is that the 'degree of confinement' of the soil under the roller is low and the potential increase in stress (σ) with the distance from the centre of the roller (s), $\Delta\sigma/\Delta s$, is high. Therefore, the soil under the roller will flow until $\Delta\sigma/\Delta s$ is in equilibrium with the resistance to soil flow. Effect 2 apparently predominated for high roller load (H) at low soil water contents, causing the actual peak stresses to decrease rapidly with increasing water content of the soil. Effect 3 and possible effects of entrapped air may have played a predominant role at the highest soil water contents.

As for the laboratory experiment (Fig. 3), the soil water content at p_m=-10 kPa (m_{-10}) clearly increased with increasing m_d. This caused the air-filled porosity ($\phi_{a,-10}$) to decrease irrespective of changes in porosity. This effect was found for the U-plots too, which is per definition incorrect and must have been caused by the sampling technique used. As sampling was done usually few days after loading, the water contents during loading (m_d) and during sampling (m_s) were related. Figure 5 shows the relation between measured m_{-10} and m_d for 297 samples from U-plots, taken in 1988, 1990 and 1992. Based on these data, the measured $\phi_{a,-10}$ on U-plots was corrected for the replacement of air by water due to incorrect high m_{-10}. Whether the sampling technique also effected the measured $\phi_{a,-10}$ on the L-, M- and H-plots could not be concluded from the measurements because loading by the roller had the

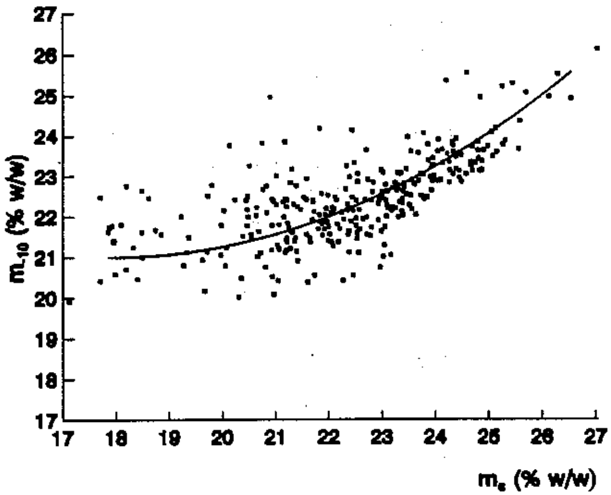

Fig. 5 Measured soil water content at p_m = -10 kPa (m_{-10}) as a function of the soil water content during sampling (m_s) for the U-plots.

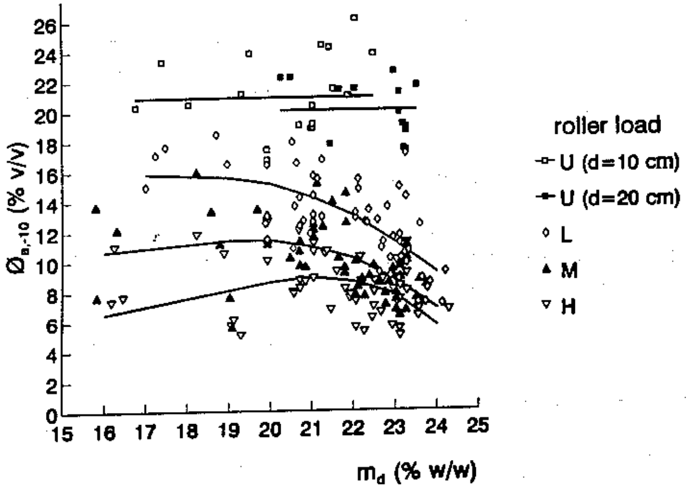

Fig. 6 Air-filled porosity at p_m = -10 kPa ($\phi_{a,-10}$) as a function of the soil water content during loading (m_d) after each loading treatment.

same effect as possible disturbances by sampling.

The effect of roller-load and m_d on $\phi_{a,-10}$, with corrected values for U, is presented in Figure 6. Again, increasing the roller-load clearly caused $\phi_{a,-10}$ to decrease. The effect of m_d on $\phi_{a,-10}$ was about proportional to the effect on ϕ up to a m_d of 20 %. For m_d > 20%, the 'm_{-10}-effect' caused a more rapid decrease of $\phi_{a,-10}$ than would be expected from the porosity. The overall effect of m_d was of interest for crop growth for the L-load ($\phi_{a,-10}$ range 8-17 %) and, to a lesser degree, for the M-load ($\phi_{a,-10}$ range 6-12.5 %), while the air-filled porosities after load H ($\phi_{a,-10}$ range 5-10 %) were all too low to be interesting.

Comparison of roller and uniaxial loading

As a basis for comparing different types of loadings by wheels, one may evaluate the effect at fixed wheel-width, wheel-load and forward speed. Thus, the L-, M-, and H-loads on the roller may be expressed as 2.25, 4.25 and 7.25 Mg m^{-1} respectively at a speed of 1 m s^{-1}. Assuming a maximum soil-tyre contact length of 0.5 m for the simulated ideal tyre, 1 m wide, having a uniform contact stress distribution and a forward speed of 1 m s^{-1}, the uniaxial stresses, equivalent to L, M an H would be 45, 85 and 145 kPa respectively, each exerted during 0.5 s. The uniaxial compression tests reported here were performed with immediate retraction of the piston after reaching the target pressure. On the other hand, the compression speed was rather low as compared to what occurs under wheels. For these reasons, a quantitative comparison of the effects of roller and uniaxial load cannot be made. Therefore, relative comparison was made only.

The resulting ϕ and $\phi_{a,-10}$ after uniaxial loading and roller loading in the field are presented

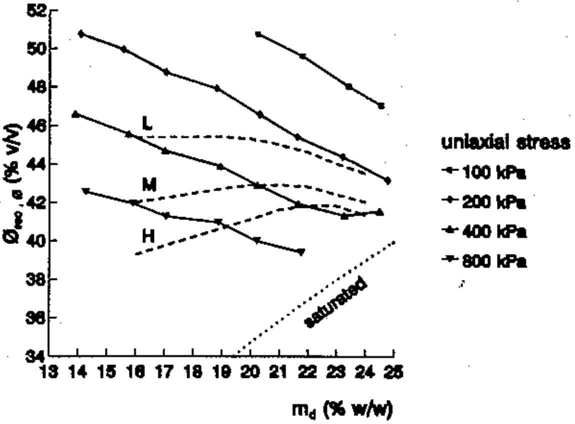

Fig. 7 Porosity (ϕ) after uniaxial (solid line) and roller (dashed line) loadings as a function of the water content during loading (m_d).

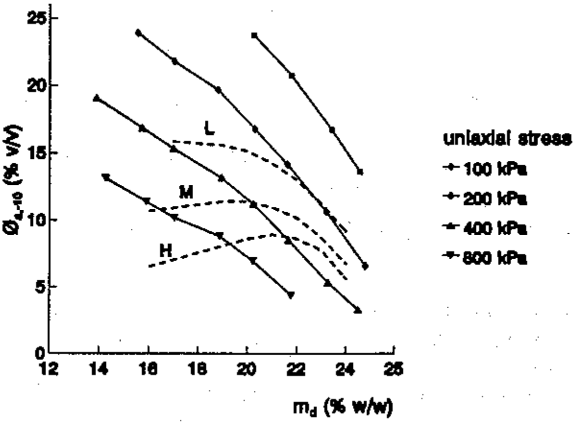

Fig. 8 Air-filled porosity at p_m = -10 kPa ($\phi_{a,-10}$) after uniaxial (solid line) and roller (dashed line) loadings as a function of the water content during loading (m_d).

in Figures 7 and 8, respectively. Both increases of uniaxial stress and roller-load are clearly causing a decrease in ϕ and $\phi_{a,-10}$. The major differences between the roller-curves and the uniaxial-curves result from the effect of m_d. For wet soil the roller-curves are similar, but with relatively less effect of roller-load on ϕ and $\phi_{a,-10}$ than that of uniaxial stress. For m_d < 23 %, the roller-curves diverge from the uniaxial-curves downwards, indicating that, with decreasing m_d, the roller compacts the soil increasingly effective as compared to uniaxial loading.

CONCLUSIONS

- Porosity and air-filled porosity at -10 kPa matric water pressure decreased, both with increasing roller-load and uniaxial stress. A similar effect, of the same magnitude, occurred due to an increasing soil water content during uniaxial loading. The soil water content had less effect for roller loading; here, the water content - porosity curves showed a maximum at a certain soil water content. This difference in effect between the two types of loading can be explained by the 'degree of confinement' of the soil during loading.
- The air-filled porosity at -10 kPa matric water pressure decreases more than proportional to the porosity by wet loading. This is caused by an increase in water content at -10 kPa matric water pressure (% w/w) with increasing water content during loading, which proved to be practically independent of the load or type of loading.

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GUIDES ON THE SUSCEPTIBILITY OF SOILS TO EXCESSIVE COMPACTION

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ABSTRACT

The paper discusses results of laboratory and simulation studies (a) on the effects of applied stress and soil wetness on soil physical properties and root growth parameters that characterize excessive compaction and (b) presents a method to characterize and classify soils as to their susceptibility to excessive compaction. Laboratory studies included three coarse-textured and four fine- textured soils. Measurements were air permeability, saturated hydraulic conductivity, water retention cbaracteristics, gas diffusion coefficient, penetration resistance, and maize (*Zea mays* L.) seedling root growth for a combination of four applied stresses and four soil wetness conditions at the time of compaction.

Two sets of criterion are defined to delineate stresses that cause excessive compaction: (a) a stress that increases the penetration resistance of soil to >2 MPa (root growth stops), or a stress that reduces the diffusion of oxygen to nearly zero (air-filled porosity<10%); (b) a stress that results in corn seedling root growth to less than 0.1 cm hr^{-1} or a stress that reduces aerobic microbial activities to less than optimal (degree of saturation less than 60%).

The database from the present study show that above criteria of excessive compaction were generally applicable to fine-textured soils. For the coarse-textured soils, effect of compaction is more in-terms of an increase in soil resistance and a lack of sufficient available water for plant growth. A procedure based on the deepest penetration of soil and plant limiting conditions is presented that rank soils as to their susceptibility to excessive compaction. The paper also outlines arguments for the time a soil remains wet due to compaction as an additional criterion for defining excessive compaction.

INTRODUCTION

Compaction of soil is a problem of worldwide concern because of (a) larger tractors, tillage, and harvesting equipment; (b) increases in intensive cropping practice; and (c) new lands being brought into cultivation, particularly in the tropics. Between 1948 and 1968 the average weight of tractors in the United States increased from 2.7 to 4.5 tons (1). At present, the average is 6.8 tons, with larger units weighing more than 22.4 tons. With larger, heavier field equipment and wider wheels, compaction of soil has increased at depths below the usual tilled zone of approximately 20 cm (2, 3). This is of particular concern because it is difficult and costly to loosen the soil at these greater depths.

Currently limited information exists on the effects of compaction on most soil physical properties and processes. Bulk density has often heen used as an indicator of excessive

compaction. In reality, primary indicator of excessive compaction is not the bulk density but those soil physical properties which directly control flow mechanisms or soil mechanical behavior (4). The authors of this paper suggested following parameters and their corresponding processes to characterize excessive soil compaction (4, 5, 6):
--air permeability / gaseous exchange
--diffusion coefficient / gaseous exchange
--hydraulic conductivity / water flow
--pore size distribution and water retention / water flow
--soil penetration resistance / root growth
--soil strength / erosion processes
The underlying question is what level of a given parameter defines excessive compaction. The objectives of study were: (a) to develop a data base on the effects of soil wetness and applied stress on soil physical properties and root growth, and (b) to use this data base for developing a procedure that characterizes and classifies soils as to their susceptibility to excessive compaction.

MATERIALS AND METHODS

Database on the effects of soil wetness and applied stress on soil physical properties and root growth were developed using bulk samples of surface soils acquired from seven different locations in the United States. The soils/locations were Cecil ls (Typic Hapludults) from Auburn, AL; Holtville sic (Typic Torrifluvents) from Brawley, CA; Webster cl (Typic Haplaquolls) from Waseca, MN; Sharpsburg sicl (Typic Argiudolls) from Lincoln, NE; Blount sicl (Aeric Ochraqualfs) from Columbus, OH; Norfolk ls (Typic Paleudults) from Florence, SC; and Miles ls (Udic Paleustalfs) from Vernon, TX. The soils are representative of areas where soil compaction is a major problem. Samples were air dried, ground and passed through a 2 mm sieve. Large (2 to 3 kg) sample of air dried soil was then loosely poured on the pressure plate, saturated over night, and then desorbed to -33 , -100, -500, -1500 kPa matric potentials in a pressure plate apparatus. Moist soil at a given matric potential was then artificially packed in a metal cylinder at a given applied stress using an Instron Universal Testing Machine. Applied mechanical stress treatments were of 49.3, 98.7, 197.4, and 394.7 kPa. Artificially packed soil cores were then used for laboratory tests. Measurements included air permeability, diffusion coefficient, hydraulic conductivity, water retention characteristics, penetration resistance and root growth of maize seedling.

RESULTS AND DISCUSSION

Based on the similarity in behavior of soils to applied stress, the results of all seven soils are grouped into: (a) coarse-textured soils and (b) fine-textured soils.

Coarse-textured soils

The soils under this group are Cecil, Miles, and Norfolk loamy sands. Briefly, bulk density increased whereas differences in porosity, void ratio, and air-filled porosity decreased with an increase in applied stress. The effect of soil wetness at the time of compaction on soil mechanical properties was minimal. Water retention characteristics of each soil were similar irrespective of applied stress and soil wetness at the time of compaction. Both air permeabilities and saturated hydraulic conductivities decreased with an increase in applied stress. Air permeabilities and saturated hydraulic conductivity linearly increased with an increase in air-filled porosity and total porosity, respectively. Effect of soil wetness at the time of compaction on both air permeabilities and saturated hydraulic conductivities was negligible. Resistance of soils to cone penetrometer increased with an increase in applied stress, with an increase in bulk density and with a decrease in soil wetness. Penetration resistance of all three soils at four applied stresses and four soil matric potentials was less than 2 MPa, a value identified in the literature as a critical limit above which the root growth stops (7). Root growth of maize seedlings decreased with an increase in applied stress, bulk density or penetration resistance. Root growth also decreased with a decrease in soil matric potential. At soil matric potential of -500 and -1500 kPa, root growth was always less than 0.1 cm hr^{-1} for all applied stresses.

Fine-textured soils
The soils in this group are Blount silty clay loam, Holtville silty clay, Sharpsburg silty clay loam, and Webster clay loam. Briefly, the bulk density increased and other mechanical properties decreased with an increase in applied stress. At a given applied stress, the effect of soil matric potential at the time of compaction on mechanical properties varied with soil type. For example, Webster and Blount soils with about 28 percent clay had a very small effect of soil wetness on soil mechanical properties whereas Sharpsburg and Holtville with 37 and 47 percent clay, respectively, the effect of soil wetness on soil mechanical properties was much greater. At a given soil wetness at the time of compaction, water retention increased by about 10 to 15 percent with an increase in applied stress from 49 to 395 kPa.

Both air permeability and saturated hydraulic conductivity decreased with an increase in applied stress but the effect of soil wetness at the time of compaction varied with soil type. Except at low values of air-filled porosity and total porosity, both air permeability and saturated hydraulic conductivity of each soil were uniquely related to air-filled porosity and total porosity, respectively. Diffusion coefficient measured on Blount and Sharpsburg soils decreased with an increase in applied stress and soil wetness. Diffusion coefficient increased with an increase in air-filled porosity and was uniquely related to air-filled porosity irrespective of applied stress and soil matric potential at the time of compaction.

Resistance of all four fine-textured soils to probe penetration increased with an increase in applied stress and bulk density, however, the effect of soil wetness at the time of compaction was small on low clay content soils (Webster and Blount). Except for applied stress of 395 kPa at a soil matric potential of -33, -100, -500 kPa, penetration resistance was always less than 2 MPa, a value above which root growth stops. Root growth decreased with an increase in applied stress, bulk density, penetration resistance and soil matric potential. Root growth rate was always less than 0.1 cm hr^{-1} when the applied stress was 395 kPa and the soil matric potential was less than -500 kPa. Root growth rate of Holtville was less than 0.1 cm hr^{-1} for all applied stresses and soil matric potentials.

Criterion of excessive compaction
Two sets of criterion are used in this study for defining stresses that cause excessive compaction. First set of criterion considers those stresses as excessive which result in soil conditions that completely stop root growth, root respiration or aerobic microbial activities. The above criterion when translated into measurable parameters defines excessive compaction as those when soil resistance to steel probe penetration is above 2 MPa (the root growth stops) and when the air- filed porosity is less than 10 percent (the gas diffusion is zero and root respiration and aerobic microbial activities are impaired). Second set of criterion assumes that an applied stress is excessive if that stress creates soil conditions that reduces the rate of root

growth to less than 0.1 cm hr^{-1} or reduces the aerobic microbial activity to less than optimum. Although selection of 0.1 cm hr^{-1} root growth rate for defining excessive compaction is arbitrary, this assumption implies that laboratory measured root growth rates below 0.1 cm hr^{-1} are not sustainable in the field over long periods of time. The criterion of less than optimum aerobic microbial activity is based on the concepts of Linn and Doran (8) that aerobic activities are maximum at 60 percent water filled pore space (degree of saturation) and the anaerobic processes increases rapidly as the degree of saturation increases above 60 percent. Based on this criterion, we defined those stresses as excessive which resulted in the degree of saturation to greater than 60 percent. Based on earlier studies of the authors on pore water pressure changes during compaction (9), an additional criterion on the degradation of soil aggregates due to excessive compaction was also included in the classification scheme. This criterion refers to the stress above which soil aggregates shear and the resulting pore water pressure changes to less negative values. The data from the present study showed that above criterion of excessive compaction were generally applicable to fine-textured soil. The major consequences of excessive compaction in coarse-textured soils were an increase in soil resistance to root growth and a lack of sufficient available water for plant growth.

Using the above criterion of excessive compaction and the output of iso-stress lines from our earlier compaction model, a procedure is developed that classifies soils according to their susceptibility to excessive compaction. The procedure converts the iso-stress lines to iso-bulk density lines and then uses the deepest penetration of soil and plant limiting conditions to identify the degree of excessive compaction for a given soil type at a given wetness and applied stress conditions. An application of the procedure showed that for a given applied stress and soil wetness condition, Sharpsburg silty clay loam was more susceptible to excessive compaction followed by Blount silty clay loam and Webster clay loam.

Effect of soil compaction on soil wetness

As demonstrated above, applied stress and soil wetness are intricately linked in defining excessive soil compaction. Although the effects of applied stress is much greater than those of soil wetness, one still needs to know soil wetness in order to delineate applied stresses that are not conducive to excessive compaction. Of course, soil wetness at a given time and place depends upon the hydraulic properties of the soil and the climate of the area. To the authors knowledge, no long-term daily soil wetness records are available especially for compaction prone soils. The objective of this part of the study was to evaluate how soil compaction affects soil wetness. In this study, we used a soil water balance model (SWBM) to simulate the daily probability of soil wetness for three soils (Blount, Sharpsburg and Webster) at two applied stresses.

The SWBM code was written by Nieber and Lopez-Bakovic (10) and considers various hydrologic processes like runoff, infiltration, plant transpiration, soil evaporation and percolation in calculating the soil wetness. Soil inputs needed for the model are the soil hydraulic properties, curve number, amount of rainfall or irrigation, Ritchie's soil evaporation parameter, starting and ending dates of simulation, soil depth, and initial soil water content. Plant and climate inputs include leaf area index, total root depth, rainfall amount, maximum and minimum daily temperatures, daily solar radiation and alhedo. Output of interest in our study was the daily water content of each soil layer.

For our simulation, we divided the soil profile into four soil layers (0 to 20, 20 to 40, 40 to 100, and 100 to 400 cm) and assumed that the hydraulic properties of all soil layers were similar. Climate inputs were internally generated by a climate generator (11) corresponding to the location closest to where the soil sample were collected. We assumed an albedo of 0.1 for early spring conditions. The simulations were run for 18 years (1960-77) starting on 1 April through 31 May of each year. At the start of each year's simulation, it was assumed that the soil water content corresponded to the field capacity water content (soil matric potential= -33 kPa). Hydraulic properties included the water retention curve and the saturated hydraulic conductivity. Simulations were run for applied stress of 49 and 395 kPa. It was assumed that the hydraulic properties of the whole profile corresponded to the laboratory measured hydraulic characteristics of soil sample that has been subjected to the applied stress of 49 or 395 kPa.

As expected, at any given probability, increasing the applied stress from 49 to 395 kPa increased the matric potential of a given soil. In other words, soil is wetter at higher applied stress. This is expected considering higher applied stress reduces soil hydraulic conductivity and slows drainage. The data also shows that effect of increasing the stress from 49 to 395 kPa on soil matric potential is much greater on Sharpsburg silty clay loam followed by Blount silty clay loam and Webster clay loam. This is due to a combination of both greater reduction in soil hydraulic properties of Sharpsburg and Blount soils at higher applied stress and also due to the differences in weather conditions between different locations. Since wetness and applied stress for a given soil type will vary due to variation in weather conditions and variation in field equipment, respectively, it is suggested that the classification procedure described earlier be altered to describes the degree of excessive soil compaction on a probability basis.

Besides an increase in the absolute wetness of a soil, another effect of excessive soil compaction is an increase in time the soil remains wet after rainfall. Thus, output from SWBM was used to evaluate this question. The analysis showed that in defining excessive compaction one also needs to consider the number of days the soil remains wet and thus cause economic loss in term of delayed field operations. Therefore, the criteria of excessive compaction could encompass a soil matric potential above which soil is considered excessively wet (i. e. the soil cannot be tilled / trafficked), and the level of consecutive days with its corresponding probability that will be acceptable in a given farming situation. A crude rule of thumb could be that those applied stresses that increase the probabilities of soil matric potential being greater than -33 kPa to above 25 percent for three consecutive day can be defined as excessive applied stress. The analysis showed that when applied stresses is increased from 49 to 395 kPa, the greatest increase in the probability of soil matric potential being above -33 kPa for consecutive 3 days resulted for Sharpsburg silty clay loam, followed by Blount silty clay loam and Webster clay loam.

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PREVENTION OF SUBSOIL COMPACTION BY TUNING THE WHEEL LOAD TO THE BEARING CAPACITY OF THE SUBSOIL

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ABSTRACT

To prevent subsoil compaction the stresses exerted on the subsoil by a wheel load must be limited to the bearing capacity of that subsoil. Stresses under two wheel loads were computed using the model SOCOMO and verified with results of field experiments. The current strength of the subsoil was measured on soil samples with standard triaxial testing equipment and used as model input to compute whether the wheel loads exceeded the bearing capacity of the subsoil or not. Vertical stresses on the subsoil, compactions and deformations were measured in field tests. One test gave such high deformations that exceeding of the bearing capacity of the subsoil was evident. In the other test the bearing capacity proved to be sufficient. Both results were in agreement with the model computations, indicating that allowable wheel load in relation to wheel equipment and bearing capacity of the soil can be calculated and subsoil compaction prevented.

INTRODUCTION

For economic reasons capacities of farm machinery and cultivation units are still ever growing resulting in high wheel loads making the physical soil quality seriously threatened by soil compaction. Subsoil compaction needs special attention because it can only be remedied with great effort and a high energy input. Moreover, loosened soil is highly susceptible to recompaction. Scarce continuous macropores in the primary compacted layer are lacking in the recompacted layer (1). This makes it necessary to loosen the subsoil every four to five years. This means that subsoil loosening results in decreasing the quality of the soil physical and soil mechanical properties and ends in a system of regular subsoil loosening. According to (2), (3) and (4) not only compaction, but also large deformations threaten soil quality, even when accompanying compactions are low to zero.
At present the technical developments offer ample possibilities to improve the design of farm machinery, particulary the wheel equipment, in a way that severe compaction and deformation of the subsoil can be prevented. Adjustment of wheel equipment (number, size, width and inflation pressure of tyres) and wheel load to the prevailing soil strength conditions is more and more considered as a very promising mean to prevent soil compaction (5, 6, 7, 8, 9). A model that computes whether the subsoil will be overloaded by a certain wheel equipment or not is needed to arrive to a better tuning of loads from farm machinery to the bearing capacity of subsoils, which varies in time and space depending on soil texture, bulk density, and moisture conditions.
It is investigated whether the model SOCOMO (6, 10) can be used to calculate allowable wheel loads. Results of an earlier field traffic experiment (7) were used to verify the model. The strength parameters of the subsoil were measured with additional triaxial tests.

MATERIALS AND METHODS

Field traffic experiments

The tyres used in the experiment were:

(i) Test A: Special Ribbed (SR) 16.0/70-20 with an inflation pressure of 240 kPa, width of 0.41 m and outer diameter of 1.08 m.

(ii) Test B: Special Ribbed (SR) 20.0/70-20 with an inflation pressure of 80 kPa, width of 0.51 m and outer diameter of 1.22 m.

Both tyres have a rather smooth profile and are very common in the Netherlands under trailers and slurry tankers on towed wheels.

The tests were executed with the tyres mounted in a single-wheel device, with a controlled wheel load of 32 kN in both tests. The speed was 0.33 $m.s^{-1}$. The measured horizontal wheel load was 4.0 kPa in test A and 2.6 kPa in test B.

The experiments were conducted on a fine sandy soil containing 4.6% organic matter and 6.6% $CaCO_3$. The particle size distribution was: 2.9% < 2 µm, 31.1% between 2-50 µm, 64.4% between 50-150 mm and 1.6% > 150 µm. The thickness of the topsoil was 0.35 m.

The vertical stresses induced by the wheel load in the interface of the loose topsoil and the firm subsoil was measured with five pressure cells simultaneously in a section perpendicular to the driving direction with one cell underneath the rut centre. The vertical stress distribution on the subsoil was approximated with the five measured stress curves. By integration of this distribution the reaction force was computed. This was done to check the reliability of the measurement, because the reaction force must be equal to the wheel load applied. In tests A and B the ratio between computed reaction and wheel load applied was 1.08 and 1.04 respectively. In this paper this ratio was used to correct the measurement. Moreover, the measured stresses were increased with the vertical pressure induced by the weight of the soil on the pressure cells.

Deformations and compactions were measured with a vertical point grid, positioned into the soil profile perpendicular to the direction of wheel passage. Using stereo photography the grid was photographed before and after the test and x, y and z coordinates of each gridpoint before and after the test were measured. Then compactions and deformations were computed.

Model computations

With the model SOCOMO (SOil COmpaction MOdel, (6, 10)) stresses under the two wheel loads were computed. In the model a concentration factor ν is used which depends on the stiffness of the soil. In this study with a loosened topsoil a soft soil was assumed resulting in ν = 5 (11).

The mean normal stress in the soil-tyre contact surface of tyre A was taken 1.2 times tyre inflation pressure according to a rule of thumb given by (11). In case of tyre B a rule of thumb for low pressure tyres was used. Mean ground pressure is equal to inflation pressure plus 50 kN (6). A parabolic vertical pressure distribution over the tyre footprint is considered using a modified formula of (12):

$$p_i = [A+(B-A)(y/y_{max})^n][1-(x/x_{max})^m] \tag{1}$$

$$B = rA \tag{2}$$

$$A = p_m(n+1)(m+1)/[m(n+r)] \tag{3}$$

where A = maximum vertical pressure at footprint center
B = maximum vertical pressure at footprint sides
r = ratio of B to A
p_m = mean vertical pressure over the footprint

x,y = x and y coordinates point i, x in travel direction
x_{max},y_{max} = one-half of footprint length and width respectively
m,n = power for parabola in x and y direction respectively

To derive a parameter set with a good fit and an acceptable pressure distribution a trial and error procedure was used, in which the computed and measured vertical stresses on the subsoil were compared. The result was a parameter set with the values: $r = 0.8$, $m = 2$ and $n = 3$.

The effect of the horizontal pressure distribution in the soil-tyre contact surface on the vertical stresses on the subsoil proved to be neglectable and therefore a simple uniform distribution of the horizontal pressures was assumed.

Triaxial tests

With triaxial tests the strength of the subsoil expressed in the angle of internal friction φ and cohesion C and the strain at failure of the soil samples were determined. The triaxial tests were performed on undisturbed soil samples of 100 mm height and 50 mm in diameter, which were taken in the upper 0.20 m of the subsoil. The samples were stored on a suction plate with a water pressure of -10 kPa. Average soil moisture content was 25.1% ($g.g^{-1}$), about the same as in the field traffic experiments. The range of the dry bulk densities was 1190 to 1370 $kg.m^{-3}$. The stress and strain situation of the subsoil during the field experiment was reflected in the triaxial tests as much as possible. It was unknown to which extent water and air moved through the soil matrix during the field traffic experiments. To take two extreme possibilities in account ten drained and ten undrained triaxial tests were performed. The deformation velocity in the triaxial tests was set on 0.00435 $m.s^{-1}$. The peak strength was reached in 0.6 to 1.8 s, comparable with the traffic experiments where in approximately 1.5 s the stresses on the subsoil reached their peak value. The triaxial cell pressures used were 5, 10 and 20 kPa, fitting in the range of the minor principal stresses in the subsoil as computed with SOCOMO.

RESULTS AND DISCUSSION

The peak in the stress - strain diagrams of the drained triaxial tests was more pronounced and was reached after a somewhat smaller deformation than in the undrained tests. However, peak stresses were almost identical and the results were combined to derive the angle of internal friction φ and the cohesion C in relation to the dry bulk density (Figure 1). In most tests peak stress was reached at a deformation smaller than 5%. After unloading a rebound of approximately 1% occurred resulting in a permanent deformation of 4%.

By combining the relation in Figure 1 with the dry bulk density profiles of tests A and B in Figure 2 the strength parameters φ and C were derived for each depth, which is needed as input for SOCOMO. In test A the subsoil at a depth of 0.5 m below surface was very loose and we were forced to extend the lines in Figure 1 under the measured bulk density range to derive φ and C. The strength parameters of the loosened topsoil were determined in earlier triaxial tests resulting in $\varphi = 25^0$ and $C = 7.5$ kPa.

From Figure 3 it appears that the computed minor principal stress S_3 in test A fits in the cell pressure range used in the triaxial tests. The maximum value of S_3 in test B is 12 kPa. In Figure 4 the computed maximal vertical stresses S_v on the subsoil in test B in a cross section perpendicular to the driving direction is compared with the maximal vertical stresses measured with the five pressure cells. A good agreement was derived without being forced to use an unrealistic stress distribution in the tyre - soil interface as input in SOCOMO. The

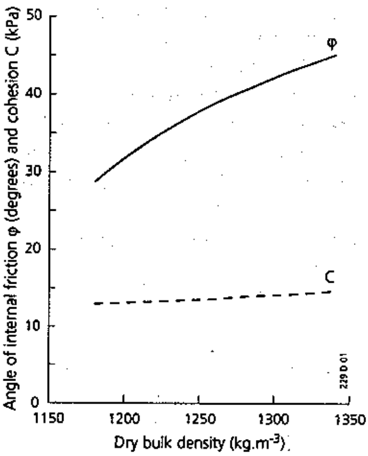

Fig. 1. Angle of internal friction φ (degrees) and cohesion C (kPa) in relation to the dry bulk density ($kg.m^{-3}$) at an average soil moisture content of 25.1% ($g.g^{-1}$) and soil water suction of 10 kPa.

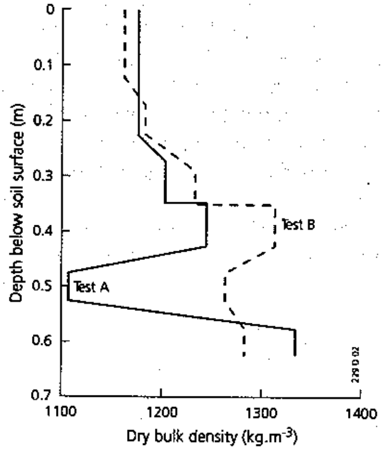

Fig. 2. Initial dry bulk density in tests A and B. The soil was loosened to a depth of 0.35 m.

computed area with plastic deformations, where the soil strength was exceeded in Figure 5 shows that in test A the wheel load was too high in comparison with the bearing capacity of the subsoil. The loose layer at a depth of 0.5 m below surface was too weak and yielded. In test B the bearing capacity of the subsoil was sufficient.

From the coordinates measured with the photographed point grid the resulting principal strains after wheel load were computed. The major principal strain ε_1 in the field tests and the vertical deformation in the triaxial tests can be compared, because in a triaxial test the vertical deformation of the sample is the major principal strain. From the triaxial tests we learned that a remaining major principal strain after loading larger than 4% is a strong indication that the strength of the soil is exceeded and plastic deformations occur.

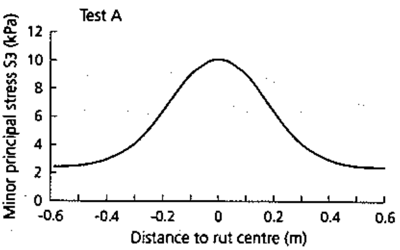

Fig. 3. Computed minor principal stress S_3 (kPa) in the topsoil-subsoil interface in test A.

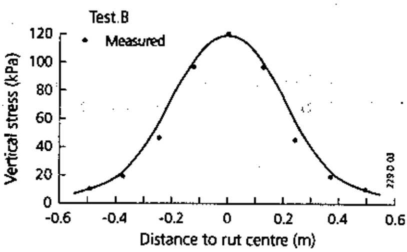

Fig. 4. Comparisment of computed and measured maximal vertical stresses on the topsoil -subsoil interface in a cross section in test B. Taking advantage of the symmetry four out of the five measured maxima could be doubled.

Figure 6 shows that in test A major principal strains ε_1 larger than 4% occured in the upper 0.10 m of the subsoil, proving that the bearing capacity of the subsoil was exceeded. In test B this was the case for a very small part of the subsoil in the centre. Bearing in mind that the grid has a pattern of 50 x 50 mm this may be accounted to the smoothening effect of the interpolation procedure between the grid points in the topsoil and the subsoil because in that interface a strong discontinuity in deformations can be expected. The conclusion is that in test B the bearing capacity was sufficient and no plastic deformations occurred in the subsoil. Comparison of Figure 5 and Figure 6 shows that in test A SOCOMO overestimated the area with plastic deformations. In test B both measured and computed area with plastic deformations were limited to the topsoil.

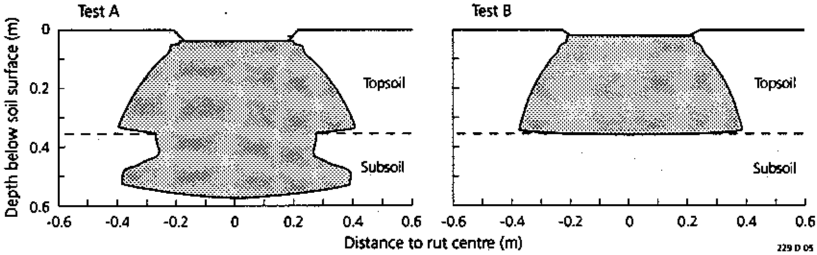

Fig. 5. Computed area with plastic deformation, where the soil strength is exceeded in thest A (tyre SR 16.0/70, inflation pressure 240 kPa) and test B (tyre SR 20.0/70, inflation pressure 80 kPa). Wheel load was in both tests 32 kN.

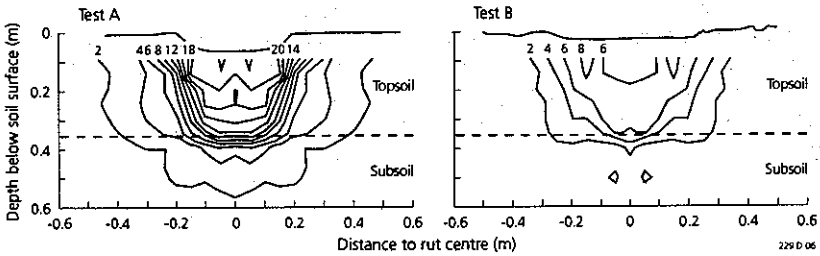

Fig. 6. Remaining major principal strain ε_1 (%) computed from soil deformations measured with a point grid. Strains larger than 4% indicate that soil strength was exceeded and plastic deformations occurred.

CONCLUSIONS

Results of SOCOMO agreed well with the measurements in the field tests.
Computations with SOCOMO offer good possibilities to adjust wheel equipment (number, size, width and inflation pressure of tyres) and wheel load to the existent bearing capacity of the subsoil. This makes it possible to design and select wheel equipment to prevent subsoil compaction.

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VARIABILITY OF INTERNAL STRUCTURE OF CLODS IN RELATION TO SOIL CONDITIONS PRIOR COMPACTION, EFFECT ON SOIL STRENGTH

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ABSTRACT

Field observations and laboratory experiments were combined to analyse the heterogeneity of soil structure in tilled layers. A morphological classification of the internal structure of clods sampled in the tilled layer was defined and correlated to porosity and tensile strength measurements.
In order to understand what were the compaction conditions leading to the various morphological features observed, compaction tests were performed on remoulded samples having various initial aggregate size distributions and water contents. The resulting soil strength of these artificial clods was assessed. Results obtained from artificial and natural clods were then compared to validate the proposed morphological classification, related to prior compaction process.

INTRODUCTION

Compaction induced by wheeling, and subsequent tillage operations affect soil structure and introduce spatial variability in processes, such as water, gas and heat transport, as well as root growth and establishment, in the tilled layers. Soil conditions at the time of operating in the fields are partly responsible for the intensity of structure changes and their further consequences at the crop level.
Different problems due to the presence of massive clods in the tilled layers have been demonstrated by various authors ; they deal for instance, with : poor seed bed preparation (1) poor seedling emergence (2) bad efficiency of the root system in uptaking water or nutrients (3).
If several works have been presented on clods strength (4), only a few have tried to relate compaction conditions, clods porosity and compaction-induced strength, but none has studied the variability of internal structure of clods and its relations to previous compaction conditions and induced strength.

MATERIAL AND METHODS

Site and Soil

A field experiment was performed in Grignon in the northern Paris Basin (Institut National Agronomique Paris-Grignon) where regular tillage operations were performed : mould board ploughing, and secondary tillage. The soil was a silt loam (Tab. 1).

Table 1 Particle size distribution

0-2 µm	2-20 µm	20-50 µm	50-200 µm	200-2000 µm	Carbon	$CaCO_3$
23.8 %	22.1 %	45.4 %	6.9 %	1.8 %	1.53 %	0.8 %

Sampling methodology and morphology criteria

Soil structure is defined by the spatial distribution of the constitutive elements and by the honds which exists in between those elements.

Different scales of organisation are to be distinguished :

- the organisation within the tilled layers, (Fig. 1) where different horizons (H0 = seed bed; H5 = ploughed layer excluding H0; H6 = plough pan; P1 = subsoil) and different lateral zones (L3 = tilled without any recent compaction, L2 = H5 compacted by wheelings having occurred before secondary tillage, and L1 = compacted by wheelings having occurred after tillage) can be distinguished (5).
- the packing of clods and aggregates defining the structural level (6), and
- the packing of elementary particles defining the textural level (7).

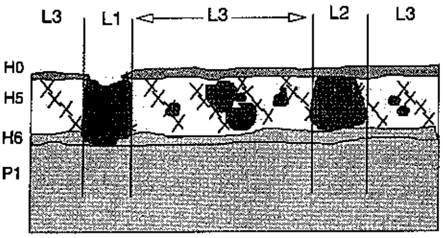

Fig. 1 - Horizontal and lateral partition in the profile (5)

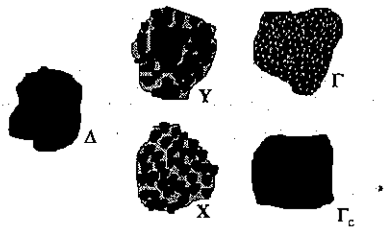

Fig. 2 - Clods morphology classification (6)

1350 clods, having 4 - 5 cm diameter, were sampled from each zone in the horizon H5 of the profile, and classified according to their internal structure (Fig. 2) observed on a rupture plane:

- Δ were massive with no visible pores, and offered a high soil strength.
- X were made out of smaller clods (10 - 20 mm) and aggregates (2-4 mm) having Δ properties and which contours were still visible.
- Y were made out of small aggregates (2-4 mm) having Δ properties, rather uniformly calibrated, which contours were visible.
- Γ were made out of agglomerated fine tilth (<1 mm) with visible packing voids.
- Γc. are made out of compacted agglomerated fine tilth (<1 mm) which contours are still visible.

Their volume was measured by liquid displacement after wax coating, their bulk density determined, and their structural porosity (n_s) or structural void ratio (e_s) assessed.
Various size of aggregates (1-2 mm ; 2-3 mm ; 5-10 mm), having Δ properties, were sampled in the same site to allow different soil testing procedures.

COMPACTION PROCEDURE AND SOIL STRENGTH ASSESSMENT

Confined uniaxial compaction tests, with short time of pressure application (≈ 1 minute), were performed to analyse in which conditions (compaction procedures & soil conditions) Δ clods could have been obtained.

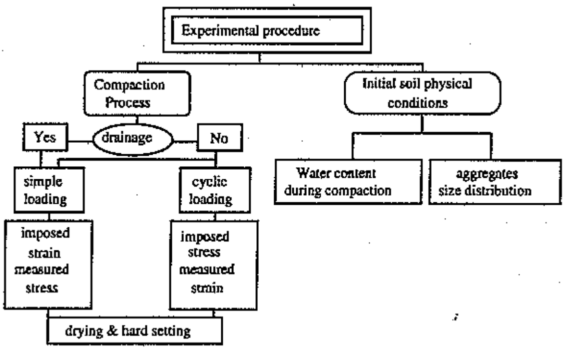

Fig. 3 - Experimental factors of variation of clods internal structure.

Soil strength was assessed by measuring tensile strength on both natural clods and compacted samples (8). Natural clods were spherically shaped by mechanical abrasion and their tensile strength assessed by crushing test. Cylindrical compacted samples were submitted to the Brazilian test.

RESULTS

Natural clods

The morphological classification of clods appeared to be in good agreement with the measures of bulk densities and related structural porosities (Table 2) which were ranked accordingly to the size and quantity of the smaller constitutive aggregates having Δ properties (Fig. 2).

Table 2. Distributions of structural porosities (n_S) and tensile strength (^{G}To) for each morphology.

Morphology	Δ	Γc	Y	X	Γ
clods number	643	58	162	61	91
Mean n_S	8.3	14.0	14.1	17.7	18.5
std.	4.10	2.10	2.70	3.70	4.20
Mean ^{G}To	6.79	3.45	2.87	2.69	2.19
std	1.37	1.20	0.97	0.66	0.90

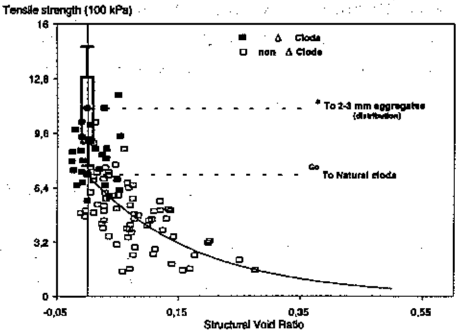

Fig. 4 - Tensile strength (100 kPa) of individual clods having various morphologies.

These results, obtained on natural clods (Fig. 4) were consistent with previous results obtained in laboratory conditions (8), where part of the variability of the overall strength for a given structural void ratio has been shown to be dependent on the conditions at which compaction occurred. In Fig. 4 it appears that the strengths values for Δ clods remained mostly inferior to textural tensile strength (9) i.e. strength measured at a textural level (2-3 mm aggregates). Thus compaction in the field has been unable to lead to the organisation observed at textural level including both packing and bonding.

Compacted samples

There was no visible effect of the constitutive aggregates size distribution on the (P, W) relationship allowing to reach a given structural void ratio. Fig. 5 shows the example of this relationship for $e_s = 0.1$.

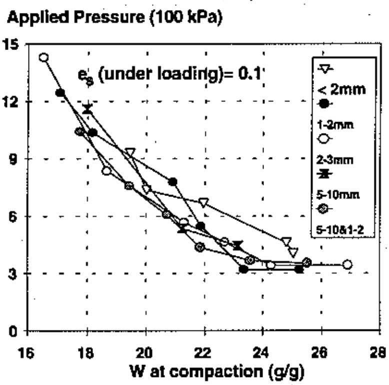

Fig. 5 - Relationship between applied pressures (P) and water contents (W) at compaction allowing compaction down to a structural void ratio of 0.1.

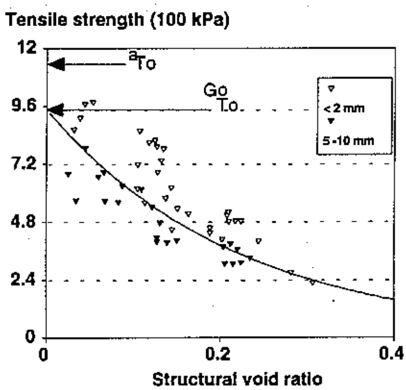

Fig. 6 - Effect of the diameter of the constitutive aggregates on the tensile strength (100 kPa) of the compacted samples

For water potential minor than -100 kPa zero structural void ratio could be obtained (Fig. 6), but only for applied pressures higher than 1400 kPa. For higher water potential (from -100 kPa to -1 kPa) the samples reached saturation meanwhile compaction process and could not attain zero structural void ratio even when high pressures were applied. Allowing a period of time for drainage by maintaining the sample under pressure, even longer than the current wheel-soil contact period, didn't provoke a higher compaction.

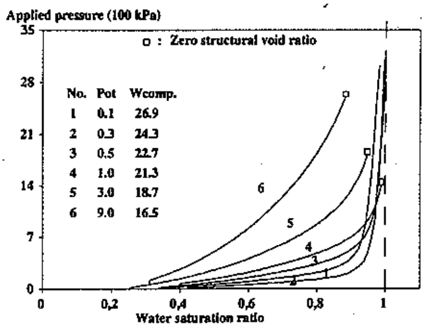

Fig. 7 - Kinetics of compaction for different water potential, effect of saturation.

Whatever were the explored exxperimental conditions of compaction, it has been impossible to create by compaction clods having a zero structural void ratio after drying. The most effective conditions would be to operate closely below the textural air entry point, but the required intensity pressures would increase when the water content decreases. Above the textural air entry point, when the textural pore space (intra aggregates) was saturated, trapped air in the structural pore space (inter aggregates) protected the soil from compaction. Apparently only the fine tilth (<2 mm) may lead to morphology Δ, the residual pore space highly devided remained unvisible by eye. The morphologies of compacted samples as well as natural clods were primarily determined by the size of the constitutive elements submited to compaction, and secondarly by the intensities of the applied loads (Fig. 8).

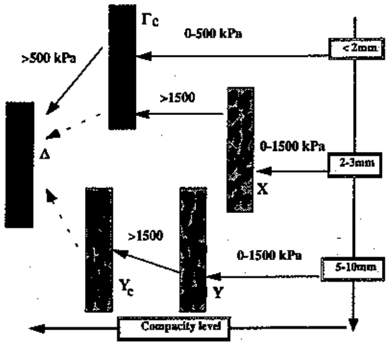

Fig. 8 - Morphologies and compaction procedures

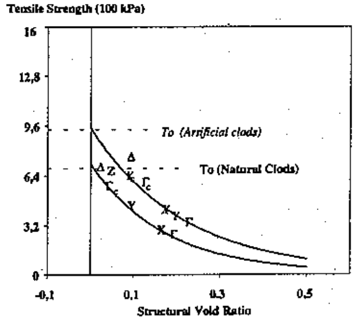

Fig. 9 - Morphologies and strengths

The lab tests had of course the limitations of being too restrictive in comparison with field conditions where (i) unconfined compression may lead to kneading, seepage and allow air to escape (ii) compaction procedure may involve more complicated combinations of wetting drying and loading processes.The relationship established previously between morphology and structural pore space induced a relationship between morphologies and level of strength and structural pore space induced a relationship between morphologies and level of strength (Fig. 9). Even if natural clods have been subjected to much more complicated scenarios including climatic processes there was a good agreement between natural and artificials clods behaviours. Nevertheless a possible wheathering can have been responsible for the lower strengths registered on natural clods as compared to compacted samples.

CONCLUSION

1) A good agreement could be obtained between the typology of internal morphology of clods, their structural porosity and related strengths.This typology is thus a good tool for field observations that may alleviate heavy procedures for sampling and measuring clods properties.
2) The highest compaction took place for water content inferior to textural air entry point value. Trapped air in the interaggregates porosity avoided severe compaction. But the dryer the soil, the higher the pressure required and the lower the compaction-induced soil strength.
3) Considering the size distribution of constitutive aggregates, the smaller the fragments, easier was the compaction, and the higher was the induced strength.

ACKNOWLEDGEMENTS

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USING X-RAY COMPUTED TOMOGRAPHY FOR STUDYING SOIL STRUCTURAL HETEROGENEITY

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ABSTRACT

Soil transport and storage processes are highly influenced by the heterogeneity of soil structure. X-ray computed tomography (CT) was used for the assessment of differences in soil structure of four topsoils by means of stepwise dividing soil cores into volume elements with edge lengths down to 0,25 x 0,25 x 1 mm and measuring/calculating the parameters Hounsfield unit and standard deviation. The results indicated that CT-scanning may be a promising tool for evaluating the heterogeneity of soil structure.

INTRODUCTION

Ecologically relevant soil processes like solute transport, storage, filtering, degradation, regeneration depend markedly on the state of soil structure. Therefore adequate tools have to be developed and used in order to quantifiy and describe soil structure in a quick and non-destructive fashion. Recently, X-ray computed tomography, originally used for medical purposes, has been applied for direct and non-destructive investigations of soil cores with reference to macroporosity (1, 2, 3), water content and bulk density distributions (4, 5, 6, 7) and earthworm activity (8).
This study is a first attempt to quantify the state of soil structural heterogeneity. Samples from 4 agricultural sites with different soil types in the range of loamy sand to clay were investigated.

MATERIALS AND METHODS

Undisturbed soil cores were taken in plexiglass cylinders (inner diameter 10 cm, height 10 cm) from Ap-horizons of sandy, silty and clayey soils (Tab. 1) with marked differences in soil structure (Fig. 1).

clay	-	homogeneous, massive (coherent) structure with fine shrinkage cracks
loamy sand	-	heterogeneous, compacted fragments and single grain structure
silt loam	-	very heterogeneous, heterogeneous aggregate size distribution
silty clay loam	-	very heterogeneous, well structured, fine aggregated, homogeneous aggregate size distribution

The samples were horizontally scanned with a Siemens Somatom Plus CT-scanner, located at the University hospital Rudolf Virchow in Berlin, at 120 kV, 330 mAs, zoom 4.0, slice thickness 1 mm and a spatial resolution of 0,25 x 0,25 x 1 mm volume elements, representing the basic voxel size. Further analyses focused on the largest possible cube within the cylinder with an edge length of 70 x 70 x 80 mm. This volume was computationally divided into smaller volume elements with edge lengths of 10, 5, 2, 1, 0,5 and 0,25 mm, respectively (9). Based on Hounsfield units (HU) for the basic voxels, average HU-values and standard deviations (SD) of larger volume elements were calculated and classified with a range of 100. For quantification of soil structural heterogeneity frequency distributions of classified HU- and SD-values and semivariance analyses were used.

Table 1 Description of soils investigated

Variant	Sampling depth cm	Textural class (USDA)	Particle size distribution Clay %	Silt %	Sand %	Dry bulk density g/cm³	Water content g / g	Organic matter %
1	20 ... 30	loamy sand (LS)	0,7	15,1	84,2	1,54	0,06*	1,6
2	20 ... 30	silt loam (SiL)	15,5	82,1	2,4	1,21	0,25*	1,7
3	20 ... 30	silty clay loam (SiCL)	39,1	52,6	8,3	1,14	0,32*	4,2
4	9 ... 19	clay (C)	54,1	37,2	8,7	1,28	0,34**	5,1

* pF 2,5 , ** pF 4,2

The measured HU-values depend on soil phase composition (solid, water, air),the relationship can be described by the equation

$$HU = sv * HU_{matrix} + av * HU_{air}$$

where sv, HU_{matrix}, av and HU_{air} denote the relative solid volume (cm^3/cm^3), the Hounsfield unit of soil matrix, the relative air volume (cm^3/cm^3) and the Hounsfield unit of air, respectively. The scale of Hounsfield units includes the range from -1000 to +3000. The two phases air and water are defined by HU-values of -1000 and 0 respectively. The soil skeleton is characterized by a HU of +3000. Hence, in the 3-phase-system it is possible to measure $-1000 < HU\text{-values} < 3000$. The specific HU-values of the matrix of loamy sand, clay, silt loam and silty clay loam are 2000, 2400, 2280 and 2260.

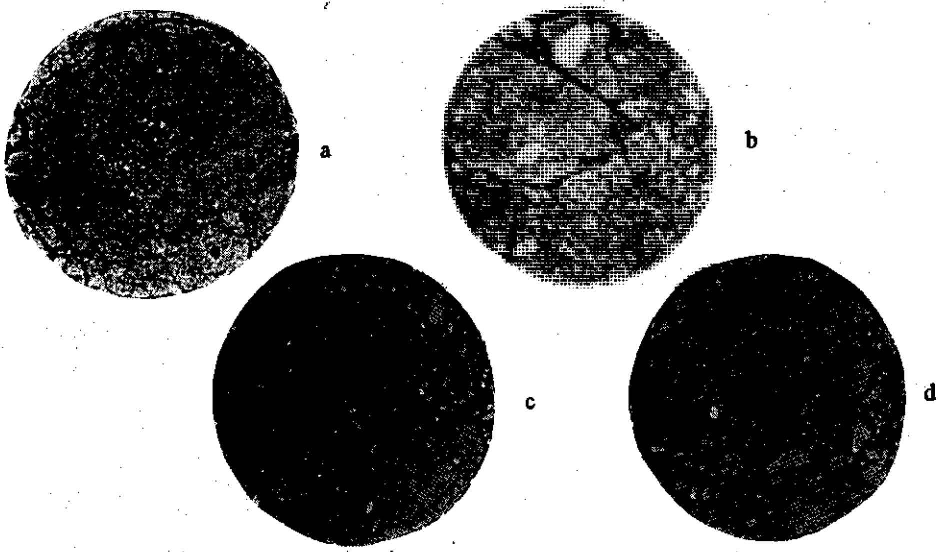

Fig. 1 Representative scan slices of the investigated clay (a), loamy sand (b), silt loam (c) and silty clay loam (d)

RESULTS AND DISCUSSION

The investigated soil cores differ markedly in particle size distribution and heterogeneity of soil structure (Fig. 1). The dry, shrunken clay is the most homogeneous soil, the loamy sand, silt loam and silty clay loam are gradually more heterogeneous.
The frequency distribution of covered HU-classes in dependence on voxel size indicates a first criterion for differences in heterogeneity of soil. The more heterogeneous a soil core is, the more HU-classes are covered and the less is the covering of dominant HU-class (Fig. 2).

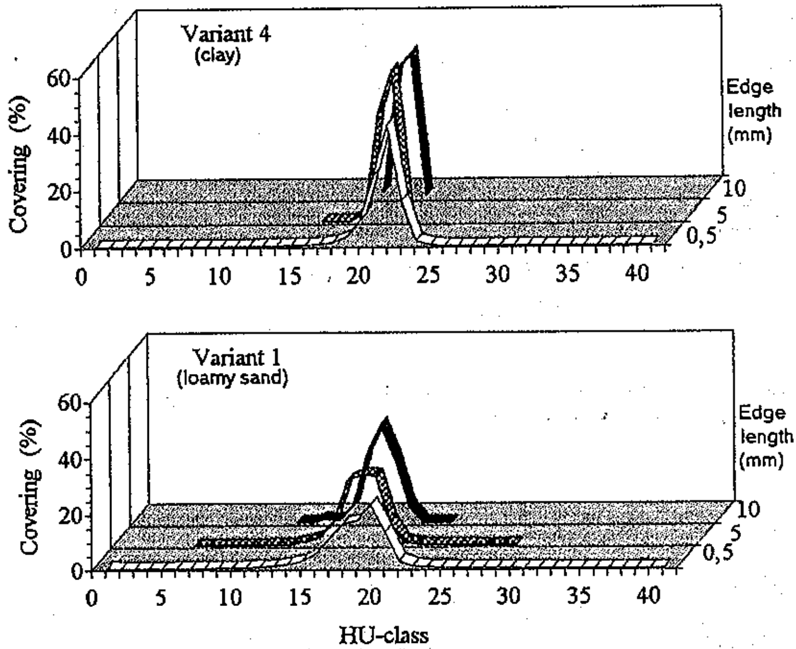

Fig. 2 Relative frequency distribution of covered HU-classes for the homogeneous clay and the more heterogeneous loamy sand, derived from different voxel sizes

The steepness of cumulative frequency curve (Degree of Heterogeneity, D_H), calculated as the quotient of covered HU-classes at 90 % and at 10 % (Fig. 3), allows to determine the following rank order from homogeneous to heterogeneous soil structural state:

	clay →	loamy sand →	silt loam →	silty clay loam
D_H	1,2	1,3	2,3	2,5

Whereas the parameter D_H characterizes the heterogeneity based on decomposition of greater volume elements in smaller one's, the standard deviation of volume elements assesses the heterogeneity of the voxels. The soil is the more homogeneous, the more voxels are located within the lowest SD-classes.
Differences in covering of the first 5 SD-classes (Fig. 4) and calculations of Weighted Mean (WM_{SD}) of all covered SD-classes (Tab. 2) show a complete conformity with the D_H regarding the rank order of heterogeneity classification. Between WM_{SD} and the voxel size exist a causal interrelationship.

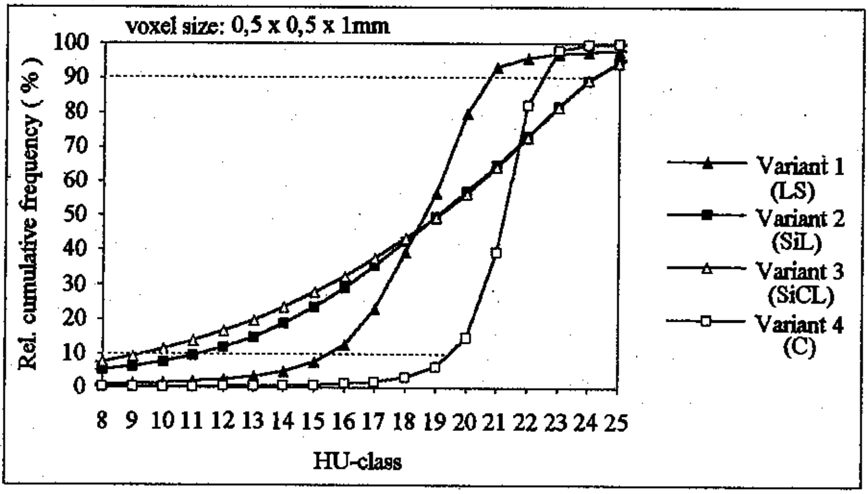

Fig. 3 Relative cumulative frequency of covered HU-classes in the range of 10 to 90 %, related to the four soil types

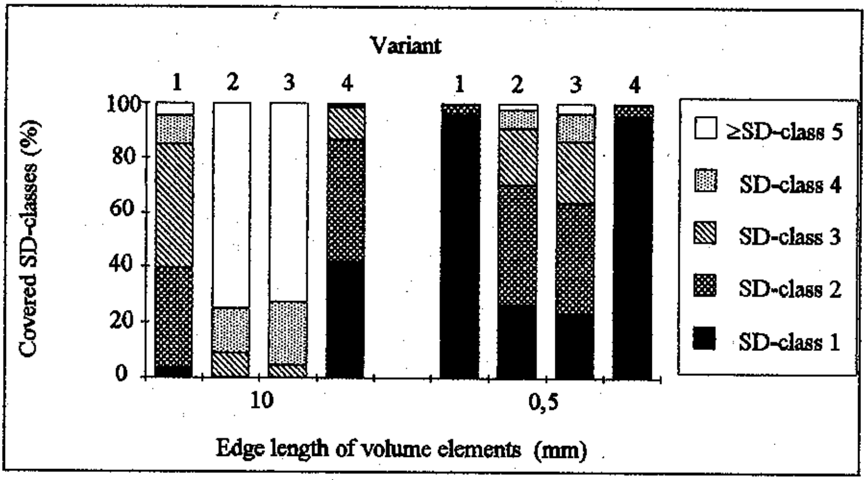

Fig. 4 Differences in covered SD-classes between the four soils, related to selected edge lengths of voxels

Table 2 Quantification of heterogeneity of soil structure by Weighted Mean of covered SD-classes (WM_{SD}) and Degree of Heterogeneity (D_H), related to different voxel sizes

Variant	Voxel size (mm)					
	10 x 10 x 10		5 x 5 x 5	1 x 1 x 1	0,5 x 0,5 x 1	
	D_H	WM_{SD}	WM_{SD}	WM_{SD}	D_H	WM_{SD}
4 (C)	1,0	125	107	63	1,2	55
1 (LS)	1,2	244	201	69	1,3	55
2 (SiL)	1,2	538	512	302	2,3	168
3 (SiCL)	1,2	615	590	341	2,5	186

The more heterogeneous a soil core is the greater are the D_H- and WM_{SD}-values. These results of quantification agree with the morphological image (Fig. 1) of scan slices. Further information about heterogeneity of soil structure, architecture of soil fabric and size of structural domain can be achieved by means of geostatistical approaches (1). Criterion of evaluation are neighbourhood considerations between volume elements over increasing distances.
HU-Semivariograms selected for the x-direction and for voxel sizes of 10 and 5 mm, show for the clay, the loamy sand, the silt loam and the silty clay loam ranges from 2.5, 1.0, 3.0 and 2.0 cm, respectively (Fig. 5).

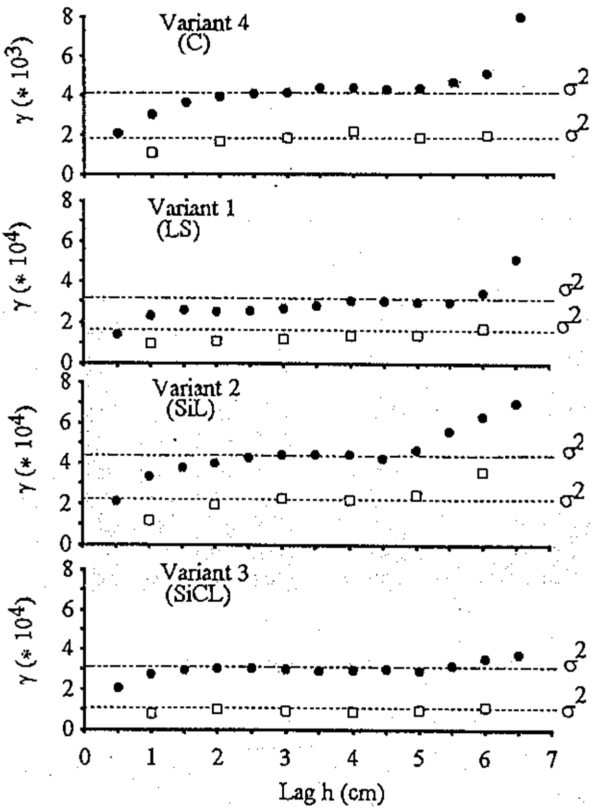

Fig. 5 3-dimensional semivariograms in x-direction for Hounsfield-units of voxels with edge length of 10 mm (□) and 5 mm (•), related to the four soils

The results for clay should be considered in view of the marked smaller semivariances and variances.The slight increase of semivariances over a large range of distances, observed for the loamy sand, may be caused by a non-isotropic distribution of structural elements, which can be found in the scan slice (Fig. 1b). The silty clay loam, which is the most heterogeneous one of the soils investigated, has in comparison to silt loam smaller semivariances and a smaller sample variance. This may be visualized by the more regular arrangements of aggregates (Fig. 1d). Moreover the silty clay loam is characterized by a smaller size of structural domain, indicated by the range and visualized with aggregate sizes.

The results indicate, that the used procedure and methology is promising to assess the heterogeneity of soil structure. Measures for characterizing the structural heterogeneity determined for different voxel sizes are

- the HU-frequency distributions and their slopes (D_H),
- the standard deviation of HU within voxels (WM_{SD}) and
- the structural domain size, identified as the range in semivariance analysis.

CONCLUSIONS

The results indicate that X-ray computed tomography is a promising tool for assessment of soil structure. The calculation of phase composition of voxels of respective sizes requires the scanning of soil cores with two different energy levels.

ACKNOWLEDGEMENTS

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FRACTAL CHARACTERIZATION OF TILLED LAYERS TO PREDICT SATURATED HYDRAULIC CONDUCTIVITY

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ABSTRACT

Fractal geometry in tilled soils can enhance potential of classical models to predict saturated hydraulic conductivity, but evidence for fractal behavior of soil properties requires more evaluation. Pore volume distribution, pore-solid interface, aggregate roughness, and aggregate mass was measured on five samples of a Normania loam. Except for aggregate mass, soil properties were fractal between defined limits. The Kozeny-Carman equation, re-derived for soils with fractal properties successfully predicted saturated hydraulic conductivity.

INTRODUCTION

Saturated hydraulic conductivity, K_{sat} is needed to characterize and predict water flow in soil. Models that estimate K_{sat} using a power law of macroporosity (1,2) or of mean particle/aggregate diameter (3) have empirically derived exponents. Fractal geometry may provide an estimate of these empirical coefficients that is related to fundamental properties of the porous medium. If the porous medium has fractal properties, the Kozeny-Carman equation becomes a power law of porosity and can be used to estimate K_{sat} (4), however, the fractal character of relevant soil properties is largely unknown.

Our objectives were to: (i) investigate the fractal behavior of soil properties necessary to predict K_{sat} in (freshly) tilled soils, (ii) predict K_{sat} for soils with fractal properties using the Kozeny-Carman equation.

KOZENY-CARMAN EQUATION

The general form of the Kozeny-Carman equation is (3,4):

$$k=c_0\phi/S_v^2 \qquad [1]$$

where k is permeability (m^2), c_o is a constant dependent on pore shape, ϕ is porosity ($m^3\ m^{-3}$), and S_v is the specific surface area expressed per unit pore volume (m^{-1}). Permeability and K_{sat} are related: $K_{sat}=[g/\mu]$ k, where g is the gravitational acceleration ($m\ s^{-2}$), μ is the kinematic viscosity ($m^2\ s^{-1}$). For water, $[g/\mu]\approx 10^7$ at 20° C. When S_v is expressed per unit bulk volume, $S=S_v\ \phi$, Eq.[1] becomes:

$$k=c_0\phi^3/S^2 \qquad [2]$$

For a fractal porous medium, the surface area, s, and pore volume, v, can be expressed as functions of the lower (r_1) and upper (r_2) limits of the pore size distribution (4) as: $s(r_2) \propto (r_2/r_1)^{2-D_{sp}}$, and $v(r_2) \propto (r_2/r_1)^{3-D_v}$, where D_{sp} and D_v are the fractal dimensions of the pore volume and pore-solid interface, respectively. According to (4), expressing S_v as s/v, Eq.[1] becomes:

$$k=c_1\phi\,(r_2/r_1)^{2[(2-D_{sp})+(D_v-3)]} \qquad [3]$$

where c_1 is a constant. Bulk volume, v_b, can be expressed: $v_b(d_2) \propto (d_2/d_1)^{3-D_c}$, where d_1 and d_2 are the upper and lower limits of the aggregate size distribution, respectively, and D_c expresses the structure of the medium at a scale larger than particle size, i.e. particle arrangement, (5). For ordered or disordered homogeneous arrangement of spheroids, $D_c=3$, (5). Analogous to the development of Eq.[3], Eq.[2] can be written as:

$$k=c_2\phi^3\,(d_2/d_1)^{2[(2-D_{sp})+(D_c-3)]} \qquad [4]$$

where c_2 is a constant. Estimations of D_c can be obtained from variations in bulk density, ρ_b, with aggregate size (5):

$$\rho_b \propto (d_m)^{D_m-D_c} \qquad [5]$$

where d_m is the mean diameter, and D_m is the fractal dimension of the mass of the porous medium: $M(r_2) \propto (d_2/d_1)^{3-D_m}$. For detailed derivations of Eqs.[3] and [4], see (4) and (5).

MATERIALS AND METHODS

Field samples and methods

Samples from two primary tillage treatments (fall chisel plow and spring disc after corn) in a Normania loam (Aquic Haplustoll) were collected from three replicates of a randomized, complete-block experiment, in the fall of 1993 at the SW. Exp. Station, Lamberton, MN. Surface sealing was prevented by placing a plastic net 10 cm above the soil surface immediately after spring tillage. Samples in each replicate x treatment were: (i) three undisturbed cores (5 cm diam. and 5 cm long) for K_{sat}, (ii) one soil column (20 cm diam. and 20 cm high) excavated, wrapped with plastic, and impregnated in place according to (6), and (iii) soil aggregates collected from the tilled layer,and subsequently air-dried. Soil samples from each replicate x treatment were adjacent to each other.

Laboratory measurement and data analysis

Field-impregnated core samples were re-impregnated under vacuum (6), and selected faces were cut with a diamond saw, polished, and photographed under fluorescent conditions under UV light. Photographs were digitized on a flatbed scanner (pixel size, 40x40 μm). Binary images of pores (black) and particles (white) were produced by gray-scale thresholding. Air-dried aggregates were hand-sieved to obtain eight fractions (mm): 36.0-20.0, 20.0-11.11, 11.11-5.66, 5.66-3.66, 3.66-2.00, 2.00-1.04, 1.04-0.54, 0.54-0.23. After subsamples from each fraction were weighed, the larger aggregates ($\geq$1.04 mm) were counted by hand, and smaller aggregates ($\leq$1.04 mm) counted using image analysis. This information was used to obtain the average aggregate weight for each fraction. About 700 aggregates from all eight fractions were used to determine roughness of the aggregates by image analysis. K_{sat} was determined by the falling-head method (7) with four or more determinations per core; the geometric mean of determinations and replicates was calculated stagewise (8). Image analysis was performed on binary images using NIH-Image (9), and NIH-ImageFractal (10). The fractal dimension of pore volume, D_v, was obtained by a box-counting technique (11). Roughness of pores and aggregates was obtained with a area-perimeter relationship (11). Total porosity was determined by pixel counting on the binary images. The mass fractal dimension, D_m, was obtained from a plot of the average weight per aggregate as a function of aggregate diameter (see above).

Measurements from the literature (8, 12) were evaluated jointly with our measurements Equation [3] was tested using measured K_{sat}, D_{sp}, D_v, and ϕ. Also, Eqs.[3] and [4] were fitted by non-linear regression to data in (8) and (12), respectively.

RESULTS AND DISCUSSION

Bulk density, ρ_b, and K_{sat} measured in packed columns for each of three aggregate diameters, d_m, in (12) are summarized in Fig. 1. Plots of ρ_b vs d_m, were fitted by linear regression to Eq.[5], with the slope=D_m-D_c. Assuming D_c=3 (spherical aggregates), D_m will vary between 2.89 to 2.85 in agreement with those in (13). Equation [4], with D_c=3.0, was fitted to the K_{sat} in Fig. 1 to obtain D_{sp} and C_2 (Table 1).

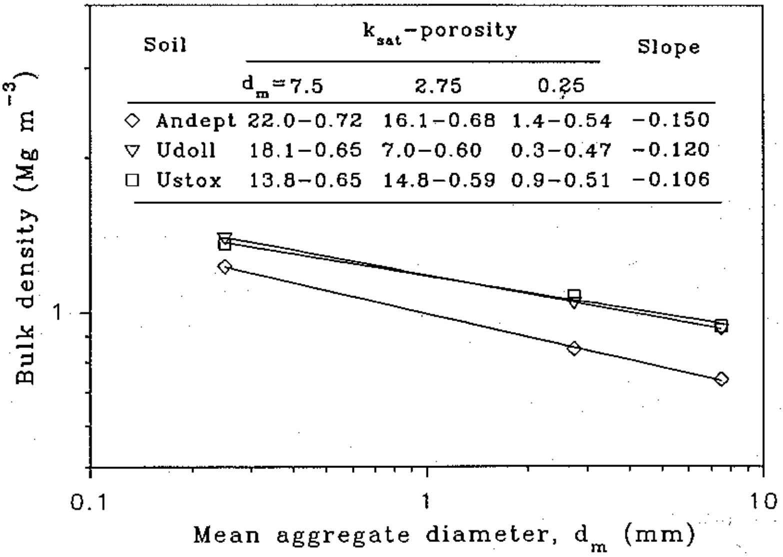

Figure 1. ρ_b vs d_m for three soils (8). Also shown: K_{sat} (μm s^{-1}), and porosity (m^3 m^{-3}). Slopes from linear regression with $r^2 \geq 0.999$.

Measured parameters for Normania loam did not show differences between tillage systems, therefore, samples were pooled across tillage treatments (Table 2). Because D_m values were larger than the theoretical maximum of 3.00 in samples 1, 2, and 4, evidence for fractal D_m is unclear. Roughness of aggregates was fractal with D_{sg} close to 2.0, which agrees with (14). Pore roughness was fractal with $D_{sp} > D_{sg}$. Pore volume had two distinctively different fractal dimensions (D_{v1} and D_{v2}) suggesting a bimodal pore size

Table 1. Fitted parameters for estimating K_{sat} in six test soils. For explanation see text.

	This paper	Logsdon et al. (8)		Larson & Padilla (12)		
	Normania	Nicollet	Waukegan	Andept	Udoll	Ustox
D_{sp}	---	2.64	2.01	2.08	2.21	2.04
C_1†	3.8x10^3	2.4x10^5	2.2x10^4	---	---	---
C_2‡	---	---	---	76	103	66

† $C_1=c_1.10^{-7}$, Eq.[3]; ‡ $C_2=c_2.10^{-7}$, Eq.[4]

distribution. Values of D_{v1} and D_{sp} together with r_2 and r_1 (Table 2) were used to predict K_{sat} with Eq.[3], with C_1 found by fitting the data to the model (Table 1).

Table 2. Measured K_{sat} and parameters used to estimate K_{sat} in Normania loam.

Sample	D_m	D_{sg}	D_{sp}	D_{v1}†	D_{v2}‡	ϕ	K_{sat}
							μm s^{-1}
1	3.08	2.06	2.35	2.75	2.22	0.22	69.8
2	3.15	2.06	2.48	2.74	2.37	0.28	67.3
3	2.97	2.07	2.46	2.68	2.40	0.30	35.4
4	3.08	2.06	2.59	2.74	2.38	0.32	28.8
5	3.00	2.07	2.35	2.74	2.21	0.22	59.1
mean r^2 §	0.999	0.998	0.904	0.999	0.999	---	---

† range (r_1-r_2): 0.064-0.51 cm; ‡ range: 0.008-0.03 cm; § r^2 of log-log plot

Data from (8) was used in this paper (Table 3), where r_1=0.04 cm is the minimum pore radius that could be recorded by methods used in (8). Table 1 shows values for D_{sp} and C_1 obtained by fitting the data for each soil to Eq.[3].

Excellent predictions of K_{sat} were obtained with Eqs.[3] and [4] (Fig. 2), although C_1 was extremely variable among soils (Table 1). In average, D_{sp} for packed columns showed the lowest values of all three cases considered (Table 1). Measured K_{sat} for topsoil was lower than for subsoil, without appreciable changes in r_2, D_v, or ϕ_m (Table 3). This indicates that descriptors of pore geometry (i.e. D_{sp}, and C_1) may be different in tilled layers as compared to subsoils.

CONCLUSIONS

Pore volume and pore-solid interface were both fractal. Roughness of aggregate surface was also fractal with $D_{sg} \approx 2.1$. Measured mass of aggregates (Normania loam) was not fractal. Bulk density for three soils and three aggregate sizes, on the other hand, indicated that mass was fractal with D_m between 2.85-2.89. The use of this information to predict K_{sat} appears promising. The Kozeny-Carman equation re-derived using fractal properties successfully predicted field and laboratory measurements of K_{sat}. The model predicted values for roughness of the pore-solid interface in packed columns that were close to the reported values of aggregate roughness. Consolidated layers showed rougher pore-solid interfaces than packed columns. This could have important implications in the prediction of K_{sat} in fresh tilled layers vs. consolidated layers. Prediction methods, or empirically determined ranges, for the physical constants in Eqs.[3] and [4] remain to be investigated.

Table 3. Measurements of r_2, ϕ_m, K_{sat}, and D_v for two soils in the data set of Logsdon et al. (8).

Soil	Treat.†	Depth	r_2‡	ϕ_m	D_v§	K_{sat}
		cm	cm	x 10^{-2}		$\mu m\ s^{-1}$
Nicollet c.l.	NT	7	0.20	0.16	2.84	9.5
	NT	32	0.17	0.14	2.82	30.2
	MB	32	0.18	0.20	2.82	56.7
	CH	32	0.30	0.22	2.89	20.4
	RT	32	0.49	0.70	2.84	35.2
Waukegan s.l.	NT	7	0.12	0.14	2.76	7.6
	NT	35	0.19	0.63	2.84	54.0
	MB	35	0.40	1.66	2.78	158.0
	A	7	0.39	1.05	2.75	70.5
	A	35	0.15	1.04	2.81	150.0
	O	35	0.40	0.80	2.82	87.3

† NT: no-till, MB: moldboard plow, CH: chisel plow, RT: ridge-till, A: alfalfa, O: oat; ‡ added by Rawls et al. (2), r_1=0.04 cm; § according to Brakensiek et al. (15)

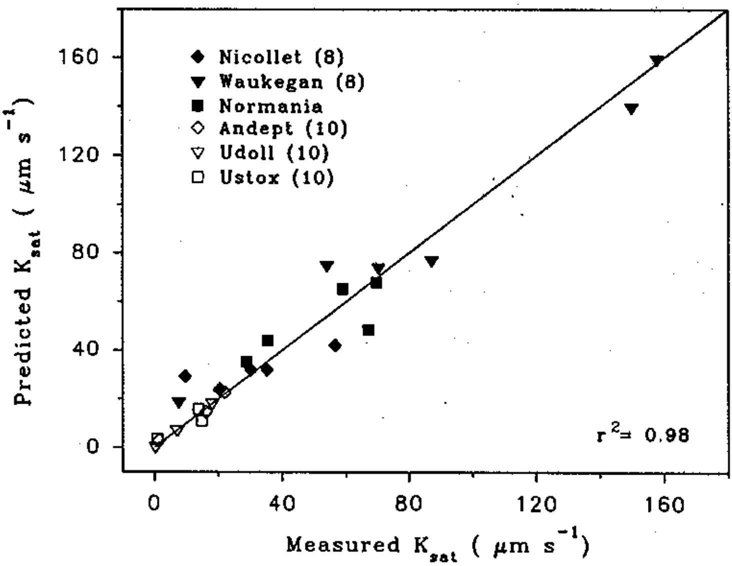

Figure 2. Measured vs predicted K_{sat} for six test soils. For explanation see text.

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THE LEAST LIMITING WATER RANGE: AN INDEX OF THE STRUCTURAL QUALITY OF SOILS FOR CROP GROWTH

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ABSTRACT

The least limiting water range, LLWR, was defined as the range in volumetric water content in which water potential, aeration and resistance to root penetration offer least limitation to plant growth. Under rainfed conditions, conditions leading to an increase in the LLWR were hypothesized to decrease the probability that plants will experience stress.

The concept of LLWR was evaluated under field conditions in 1991 to 1993. Values of LLWR were measured on soils with a range of textures and on which two tillage treatments (zero-till and conventional) had been practised for 12 years. Functions were developed to describe the influence of soil properties, profile depth and tillage on the water release curve and the water content-resistance to penetration function. Values of LLWR were then calculated for different soils, depths and tillage treatments. Water content profiles were monitored and plant growth related to the frequency in which soil water content fell outside of the LLWR. The evaluation indicated that LLWR offers considerable potential as an index of the structural quality of soils for crop production and that its value can be enhanced with statistical information on the temporal variation in soil water content.

INTRODUCTION

Growing concern regarding detrimental impacts of soil and crop management practices on the sustainable productivity of soils are highlighting the need for an index of structural quality of soils. In areas of rain fed agriculture, this index must integrate water-related factors influencing plant growth (e.g. aeration, available water, soil resistance to root penetration) and the index must be interpreted in relation to statistics on the temporal variability in soil water content.

A parameter, defined as the least limiting water range (LLWR), was evaluated as a potential index of structural quality. The parameter is based on the concept introduced by Letey (1985) of a range in volumetric water contents beyond which plant growth is limited by water potential, lack of aeration and high mechanical resistance to root penetration. Use of the parameter as an index of the structural quality of soils for crop growth is based on two hypothesis: (a) the frequency in which soil water content falls outside of the LLWR is a measure of stress imposed on the plant and when this stress occurs during sensitive growth periods the frequency is strongly correlated with yield reductions; and (b) the frequency in which soil water content falls outside of the LLWR will be directly related to the magnitude of the LLWR. The evaluation of LLWR as an index of soil structural quality involved relating LLWR and soil water content to plant response on soils with a range of structural conditions. The study was carried out for three growing seasons between 1991 and 1992 but only data from 1991 and 1992 are presented in this report.

MATERIALS AND METHODS

Field Site

The study was carried out on a field scale side-by-side comparison of zero and conventional tillage that had been maintained on a private farm near Clinton, Ontario for 11 years prior to initiation of this study. The strip traversed a landscape involving topsoils with a range of textures (1.2% to 54% clay), organic matter contents (0.5% to 11.6%) and slopes (0% to 7.8%). The site was characterized by establishing 36 study locations along a 0.5 km transect in each of the two tillage treatments. The locations were spaced according to soil type and paired between tillage treatments according to landscape position.

The site had been maintained in a corn (Zea mays L.) -soybean (Glycine max L.) -wheat (Triticum aestivum L.) rotation for 10 yr. prior to the study and was planted to corn during the study.

Water contents were recorded at 1-2 day intervals throughout the growing period at 0-0.20 m and 0-0.40 m depths using TDR probes at each of the 36 locations under each tillage treatment.

Plant growth parameters that were measured included rates of leaf extension and grain yield (only the latter parameter will be presented in this paper).

Laboratory Studies

Three hundred and sixty undisturbed cores (.05 m x 0.25 m) were collected from the 0.05-0.10 m and 0.20-0.25 m depth at each location along each transect. Each sample was equilibrated to a specific water potential and measurements of water content, soil resistance, air filled porosity and bulk density were taken. The soil water release curve and the soil resistance - water content curves were described by functions and multiple regression procedures used to relate the coefficients in the functions to bulk density, clay content and organic matter content of soil at the depth of sampling.

RESULTS AND DISCUSSION

Least Limiting Water Range

The discussion will be restricted to the zero-tillage treatment. The water release curve was described using the following function:

$\ln \theta = a + b \ln \Psi$, $r^2 = 0.90$, $n = 2520$

$a = -4.3 + 0.64 \ln \text{clay} + 0.40 \ln \text{o.m.} + 0.54 \ln \text{bd}$
$b = -0.61 + 0.11 \ln \text{clay} + 0.04 \ln \text{o.m.} + 0.16 \ln \text{bd}$

where θ is the volumetric water content ($cm^3\ cm^{-3}$), Ψ is the soil water potential (MPa), o.m. is the organic matter content (%) and bd is the bulk density ($g\ cm^{-3}$).

The soil resistance function was defined as:

$\ln SR = d + e \ln \theta + f \ln \text{bd}$, $r^2 = 0.78$, $n = 360$ where SR is the soil resistance (MPa):

$d = -2.78 - 0.09\ \text{clay} + 0.28\ \text{o.m.}$
$e = -0.54 - 0.09\ \text{clay} + 0.11\ \text{o.m.}$
$f = 1.64 + 0.08\ \text{clay} + 0.32\ \text{o.m.}$

The water content at which aeration and potential were limiting were defined as the water contents at 10% air filled porosity (a.f.p) and -1.5 MPa (wilting point, w.p.) respectively. The water content at which soil resistance was limiting was defined using a function (Dexter, 1987) relating the limiting soil resistance to potential in conjunction with the above two functions. Field capacity (f.c.) was taken as $\Psi = -0.01$ MPa.

The influence of bulk density on the water content at which each factor was a limitation is illustrated in Figure 1 for a soil with 20% clay, 4% organic matter and under no-till. These data can then be used to predict the variation in least limiting water range with bulk density for this soil (Figure 2).

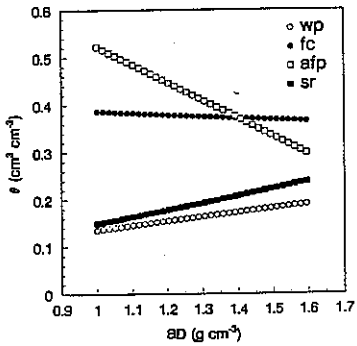


Figure 1. Variation in the limiting water content with bulk density

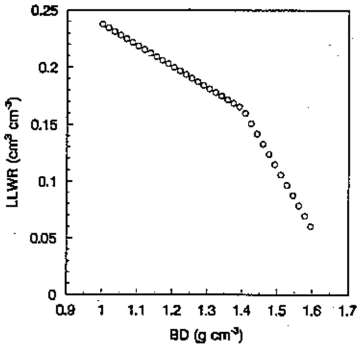


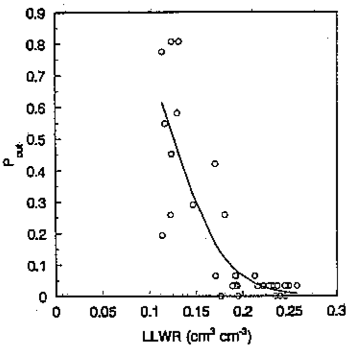
Figure 2. Variation in least limiting water range with bulk density

Soil Water Contents

Data on the temporal variation in soil water content was then used to determine the number of days during the growing period that the soil water content fell outside of the least limiting range at each location and the number of days related to crop response. The water content was converted to a binary variable (0 when inside LLWR and 1 when outside LLWR). The logistic regression was then applied to obtain the probability that the soil water content would be outside LLWR (P_{out}). The probability that the soil water content falls outside of the LLWR would be expected to be related to the amount of precipitation, the proportion of precipitation that infiltrates the soil, the rate of drainage and the LLWR. If all factors were constant across a landscape except LLWR, the probability that the water content falls outside of the LLWR would be expected to decrease with increasing LLWR. The logistic regression between P_{out} at 0-20 cm depth and the magnitude of LLWR in 1991 is:

$$P_{out} = \frac{\exp(4.64-36.61.LLWR)}{1 + \exp(4.64-36.61.LLWR)} \qquad r^2 = 0.70, n=36$$

The results are shown in Fig. 3 and follows the hypothesized trend. In 1992, however, the growing season was much wetter (precipitation in July 1992 was 77.0 mm compared to 20.4 mm in July 1991) and there was a poor correlation between P_{out} and the LLWR. The poor correlation may be due to variation across the landscape in the proportion of precipitation that infiltrates the soil and/or variation in the amount of drainage - both of which become much more important under wet conditions. The data from 1992 disprove the second hypothesis being tested and indicate that LLWR will be most useful as an index of the structural quality of soils if it is used in conjunction with data on the temporal variation in water content.



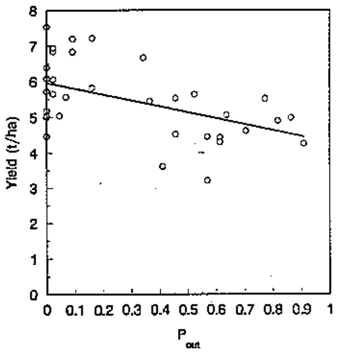


Figure 3. Variation in P_{out} with LLWR (1991)

Figure 4. Yield response to P_{out} (1992)

The value of combining soil water content data with data on LLWR as a predictor of yield is illustrated in Fig. 4 using data from 1992. A much poorer correlation existed between yield and $LLWR_{out}$. The regression equation is:

$$yield = 5.96 - 1.66*P_{out}, r^2=0.26, n=36.$$

The data in Fig. 4 are based on only the water content data from 0-0.20 m and by treating incidents of water content outside of the LLWR as equivalent throughout the growing season. Analyses are currently underway to utilize the additional data on water contents and differentially weight the occurrence of stress during critical yield-determining stages of growth.

CONCLUSIONS

The analyses to date suggest that LLWR may be a powerful way of characterizing the structural quality of soils but it will be of greatest value of combined with a statistical description of the temporal variation in soil water content - i.e. the probability of water contents falling outside of the LLWR during critical growth stages.

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SUBSOIL STRUCTURE CHARACTERISTICS OF RIVER LOWLAND CLAY SOILS WITH SHALLOW WATER TABLES

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ABSTRACT

On clay soils the subsoil structure may influence the suitability of the topsoil for tillage through its effect on the water status of the soil.
The structures of river lowland clay soils were studied by profile description and analyses of undisturbed samples from more than 100 soil profiles. The aim was to obtain parameters for soil water balance models and thematic maps, and to get information on soil structure development with time.
The significances of the following relevant parameters are presented and discussed: saturated hydraulic conductivity, dry bulk density, Atterberg limits and consistency, infiltration rate, and volume changes during shrinking and swelling. All of these parameters depend on the drainage status of the soil and the kind of land use.
Correlations are presented which demonstrate the connections between the soil structure and the measured physical parameters of the soil. Subsoils with high swelling status show mainly coherent structure with very low saturated hydraulic conductivity and infiltration rate (<0.1 m/day), low dry bulk density (0.7 - 1.0 Mg/m^3), consistency index < 0.5, and potential volumetric shrinkage of 40 - 70 % on drying.
Further work will deal with the speed and reversibility of changes in soil structural parameters as a result of cbanges in water table level after the implementation of control measures.

INTRODUCTION

Heavy lowland soils are important for agricultural production worldwide. The management of those loamy and clayey soils is difficult. Often it is limited by temporally and spatially variable waterlogging or drought. To provide sustainable agriculture and soil and water protection, knowledge on the status, interaction and possible change of soil and bydrological conditions is required. Data on moisture-dependent soil structure conditions in terms of tolerable wetness or drought are necessary for decision models to provide medium term water table control.
As the subsoil may influence the rooting depth and the water movement, its properties are of interest to calculate and control the topsoil quality.

MATERIALS AND METHODS

The study has been conducted in a large lowland area about 70 km East of Berlin. The Oderbruch area is protected by dams against flooding and is predominantly in arable use. The crop rotation has mainly consisted of cereals. All soils discussed here are Eutric Fluvisols and Eutric Gleysols after FAO-classification. Their clay content ranges of about 30 to 55%. Temporary wetness is caused mainly by groundwater recharge from the Oder

river and the adjacent pleistocene areas. The climatic conditions are characterized by annual rainfall of 450 to 550 mm and a mean annual temperature of about 8.3 °C. Potential evapotranspiration is around 500 to 560 mm on average (1).
During the springtime, descriptions and physical analyses of more than 100 soil profiles were done according to the ISSS, DIN and DVWK guidelines (2, 3, 4, 5, 6). Relevant soil diagnostic subtopics including morphology of subsoil structure, water permeability in dependence on drainage status, subsoil consistency and soil density and air volume were studied more intensively.

RESULTS AND DISCUSSION

Morphologic characterization of subsoil structure

Typical structure types often observed (Fig. 1) in clayey subsoils are:

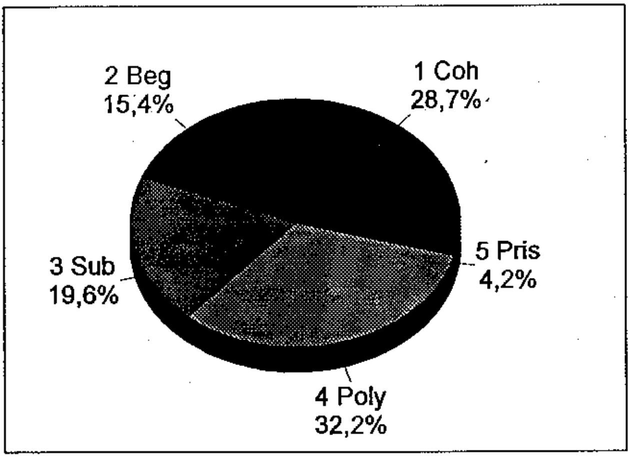
I Coherent structure (Coh)
It is typical for waterlogged soils of permanent high swelling status and occurs in the deepest part of soil profiles in the range of the permanent water table. It is mostly in accordance with the Gley-reduction Horizon (Gr).

II Structure, characterized by beginning separation of macrostructure peds (Beg).
In the soil profile it is located above the permanent water table and belongs to Horizons of both reduction and oxidation features (Gor).

III Sub-polyhedric structure (Sub).
It is typical for a medium depth in the soil profile and belongs predominantly to Gley-oxidation- (Go) or Gro-Horizons. Only during wet periods water tables may reach these layers.

IV Distinct polyhedric structure (Poly).
It is typical for more preconsolidated subsoil layers. Mostly it is located in the upper part of the subsoil. There is no influence of water table but a marked influence of loads caused by heavy machinery. But sometimes wetness by perched or surface water may occur. This structure type also occurs the in deeper part of deeper drained profiles, especially in relict Ah and Gr horizons. A distinction between this structure type and the sub-polyhedric structure is sometimes difficult and transient types may exist. The polyhedric structure has sharp edges, whilst sub-polyhedric structure is characterized by smoothed, less distinct edges (7).

Besides these relatively frequently observed structure types (Fig.1) some others occur as coarse-columnar or prismatic types typical for soils very rich in clay. In the sequence shown above these are probably located between II and III/IV. A further type seldom observed because of its transient nature is a secondary coherent type produced by compaction of the polyhedric type. After drying it changes again to the polyhedric type (7).
Hierarchical structure of peds (8) and the metamorphosis of structure are not discussed here. In the field, however, it can be observed that prismatic, sub-polyhedric and polyhedric structure may often be composed of smaller peds of the same type. This seems to be an indicator of good ecological quality, whilst the very distinct sharp-edged polyhedric structure typical of compacted zones often consists of relatively uniform parts.



Coh=Coherent, Beg=Beginning macrostructure separation, Sub=Sub-polyhedric, Poly=Distinct polyhedric, Pris=Coarse prismatic to columnar

Fig. 1: Typical distribution of subsoil structure types by morphologic description

Relationships between structure type and water conductivity

The saturated and unsaturated conductivity are important for water balance models and for the assessment of the need and choice of site improvements measures.
Table 1 shows relationships between structure types and most common classes of saturated conductivities with consideration of biological macropores. The coherent structure is characterized by very low conductivities and acts as a barrier of vertical or horizontal water movement in the soil profile. The sub-polyhedric structure has the highest conductivities whilst the polyhedric structure and its often preceding compacted status (secondary coherent structure) may hamper the vertical water movement temporally too. Land use and vegetation influence biological pore systems. On grassland higher saturated conductivities and infiltration rates are measured and more worm channels are observed than on arable land.
Infiltration rates under ponded conditions show similar relationships as shown in Table 1 (9). These conditions are typical for infiltration situations during and after heavy rains. But many water and solute transport processes occur with unsaturated and non-ponding conditions. The moisture-dependence of conductivities of clay soils investigated is shown in Fig.2. It shows the huge variability of conductivity in dependence on suction and influence of macrostructure. The right part is the course of conductivity as measured with the evaporation method (10). This and comparable methods may measure the course of conductivity in a range of about 2 to 50 kPa (pF 1.3 to pF 2.7). According to the water retention curve it is a range of macropores (11) but it does not consider the influence of the coarsest voids, cracks and vughes as they appear very distinct during the soil description in the field. Under completely saturated conditions (values on the y-axis) conductivities according to the influence of the whole macrostructure are reached. In the figure only the range of the most common conductivity classes after Table 1 is visible, but in general the highest value of the right curve transformed or fitted to the y-axis would about touch the

lowest values measured and measurable with the apparatous for the estimation of saturated conductivities (about 0.001 m/d). The conductivity in the range of 0 to 0.2 kPa is unknown and it may be, that measurements using tension infiltrometers in some cases will be able to fill in this gap. In the case of data presented here it is very likely that the rapid increase of conductivities will begin very close to the y-axis. Fig. 2 shows clearly that saturated conductivity reflects the macrostructure of clay soils. The role of macropores for the water and solute transport has been recognized for several years (e.g. 12, 13). But more emphasis should be placed on using conductivity as a structure parameter, to test its local and spatial patterns and relationships to other easily measured parameters, or to characterise macrostructure types.

Table 1: Classes of saturated conductivities

Structure type	Parameter	Class of biological macropores [1]	Mean class of saturated conductivity
I) Coherent	K_{sat} horizontal [2]	a) Very low	I Extremely low
	K_{sat} vertical	a) Very low	II Very low
II) Coherent with beginning macro-structure separation	K_{sat} horizontal	a) Very low	IV Medium
		b) Medium	V High
	K_{sat} vertical	a) Very low	IV Medium
		b) Medium	V High
III) Sub-polyhedric	K_{sat} horizontal	a) Very low	IV Medium
		b) Medium	V High
		c) High	IV Medium
	K_{sat} vertical	a) Very low	VI Very high
		b) Medium	VI Very high
		c) High	VI Very high
IV) Distinct polyhedric	K_{sat} horizontal	a) Very low	II Very low
		b) Medium	II Very low
		c) High	II Very low
	K_{sat} vertical	a) Very low	II Very low
		b) Medium	III Low
		c) High	V High

1) Classes of biological macropores: Very low <60 mm^2/m^2, medium 60-600 mm^2/m^2, high >600 mm^2/m^2

2) Core cylinder samples, vertical. Classes of saturated conductivity: Extremely low <0.02 m/d, very low 0.02-0.066 m/d, low 0.066-0.2 m/d, medium 0.2-0.66 m/d, high 0.66-2 m/d, very high >2 m/d

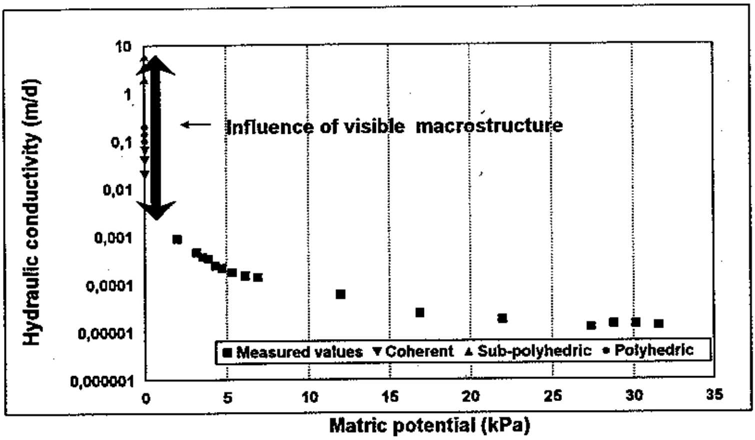


Fig. 2: Hydraulic conductivities versus suction

Water tables, structure types and further parameters

Water table depth determines the shrinking and swelling status of the subsoils leading to different structure types and soil physical conditions in and above the water table.
The ecologic quality of soil profiles is determined by the presence of any layers of limited permeability and aeration. Coherent structure types, both in the range of the water table observed primary coherent structure and the temporally observed secondary coherent structure are such barriers in the soil profile.
Though characterized by low dry bulk densities (0.7 - 1.0 Mg/m^3) which imply very high total pore volumes, the coherent soil structure shows air volumes of less than 4% and impedes not only water but root elongation too.
In deep drained soils with water tables more than 110 cm below the surface the depth characterized by the coherent primary structure acting as a barrier for water and root movement is located relatively deep in the soil profile. The soil above it contains more than 6 % of air volume and is quite well rooted.
On shallow drained arable land with water tables less than 55 cm below the surface the impeding layer is also located very shallow. Infiltration and profile drainage are hampered by a high swelling status and the absence of biological macropores. The consistency is soft or very soft (Index < 0.5) and therefore it is very sensitive to mechanical load.
The loads of heavy machinery prevent the formation of the sub-polyhedric structure. Instead temporally alternating secondary coherent structure and distinct polyhedric structure occur. The high potential volumetric shrinkage of 40 - 70 % on drying would provide improvement of the permeability and aeration status by drainage. Though technical measures of land improvement are available (14) ecological and economic constraints indicate that these field sections should be re-converted into grassland.

CONCLUSION

The relationships between water table and soil structural parameters will be applied for thematical mapping using GIS. On this basis, the requirements for regional water table control can be defined. This is an important part of ecosystem management and should be used to control the subsoil structure. Speed and reversibility of changes in soil structural parameters as a result of changes in water table level after the implementation of control measures should be investigated further.

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WETTED SOIL VOLUME UNDER A CIRCULAR SOURCE

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ABSTRACT

The disc permeameter is being used widely to characterize the hydraulic properties of the tilth layer. Therefore, it is important to describe the multidimensional flow of water away from this circular source. In this work, we use an unique approach to analyze the flow pattern, because we assume that the three-dimensional wetting fronts under the circular source are ellipsoidal. Experimental data and a numerical simulation model show that assumption is valid and wetfronts under tbe disc form ellipsoids.

INTRODUCTION

The surface characteristics of soil have a profound effect on the hydrology of tilled land (Sauer et al., 1990). For proper agricultural water management, characterization of the hydraulic properties of soils in the tillage layer is paramount. Water moves through the pores in the soil, and tillage affects pore size. Pores are smaller in tilled soils, because tillage pulverizes the soil. When the soil is not tilled, decaying roots and other organic matter create voids. Also earthworms thrive on the organic matter and their populations are greater in soil that has not been tilled.

Recognition of the importance of macropores and preferential flow in the surface layers of soil, where roots grow and soil organisms live, has led to the development of instruments that can be used in the field to control suction, and hence preferential water flow through macropores in tilled and non-tilled soils under unsaturated conditions. The first practical instrument was developed in 1981 (Clothier and White, 1981). This simple instrument is known as the sorptivity tube or tension infiltrometer. It bas evolved into the disc permeameter (Perroux and White, 1988), and, later still, into the 1/4-disc permeameter (Quadri et al., 1994), used under laboratory conditions. With these instruments, amount of macropore flow is controlled by applying water to soil at water potentials, $\Psi_o < 0$.

The disc permeameter can be used to tell us when to till. If the soil will not suck in water, as determined by the disc permeameter, then we need to till the soil. Tillage of the soil is critical, so rainwater will not sit on the surface and evaporate. We want water to go into the soil, so it will be used by plants. Little work has been done to analyze precisely the multidimensional flow of water away from a circular source of water applied at a constant negative potential, say Ψ_o. The equation of Wooding [1968; see his Eq. (64)] does describe the steady rate of 3-dimensional (3-D) infiltration from a circular pond. However, his equation applies to profiles at infinite time and does not give information about the shape of wetfronts of transient wetting. Therefore, the objective of this work is to describe mathematically the tbree-dimensional flow of water away from a disc source placed upon tbe soil's surface at constant negative potential, $\Psi_o < 0$, when the water is being applied to the soil at a steady rate, q in $mm^3\ s^{-1}$.

Problem. We use a simple, ellipsoidal description of the pattern of wetting to approximate the depth to the wet front underneath a disc permeameter, set at ψ_o, and supplying water to soil initially at water content θ_n. (θ_n is the water content referred to unit bulk volume of soil.) This simple scheme can be used as a ready-reckoner of the sampling volume that is being wetted by the permeameter.

Theory and Approximation. An axially-symmetric coordinate scheme is apt for describing the pattern of wetting under a surface disc of radius r_o. At any time t, integration of the wetted field θ, radially (r) and with depth (z) away from the disc's centre, provides the volume of water $V(t)$ that must have infiltrated from the disc,

$$V(t) = \int_0^\infty \int_0^\infty 2\pi r \, [\, \theta(r,z,t) - \theta_n \,] \;\, dr \, dz \quad . \tag{1}$$

The disc wets the soil at the surface, $0 < r < r_o$, to water content $\theta_o(\psi_o)$. If at any t, the radial extent of wetting at the surface is R, and if vertically under the disc it is Z, then if some weighted-average water content can be ascribed to the wetted field, say θ_m, it follows,

$$V(t) = 2\pi(\theta_m - \theta_n) \int_0^{Z(t)} \int_0^{R(t)} r \;\, dr \, dz \quad . \tag{2}$$

We now assume a simple form for the pattern of wetting. Working in two (spatial) dimensions with water moving away from a line source of water, Hashem (1978) found the area of the wetted soil to be well approximated by a semi-ellipse. Extending this to our case of three (spatial) dimensions, we might be able to describe the pattern of wetting around the disc by considering an axially-symmetric ellipsoid: $r^2/R^2(t)+z^2/Z^2(t)=1$. So

$$V(t) = \frac{2\pi}{3} \, (\theta_m - \theta_n) \, R^2(t) \, Z(t) \quad . \tag{3}$$

As a consequence of the 3-D geometry, the flux from a surface disc eventually becomes steady, Wooding's q_∞. After steady flow holds, with this simple descriptive model, $d(R^2Z)/dt$ will equal $3q_\infty/[2\pi(\theta_m\text{-}\theta_n)]$.

MATERIALS AND METHODS

Laboratory experiments were carried out with Manawatu fine sandy loam soil (Dystric Fluventic Eutrochrept) packed into an acrylic box at θ_n=0.1. A $^1/_4$-disc permeameter of radius r_o=60 mm, and set at ψ_o=-50 mm, was placed neatly in one corner of the box (Fig. 1). The wet fronts were visible through a clear plastic sheet placed on the outside of the box, and they were marked at different times after the beginning of the experiment (Fig. 2). This soil, at this ψ_o, has θ_o=0.375 $m^3\,m^{-3}$, sorptivity S_o=1.05 mm $s^{-1/2}$ and conductivity K_o=2x10^{-2} mm s^{-1}. The flux density from the disc soon became quasi-steady at about 0.1 mm s^{-1}. At the end of the experiment (after 585 s), soil samples were taken through the holes shown on the left-hand side of the box in Fig. 1. The water in the soil was determined gravimetrically, and values were converted to volumetric water content by multiplying by the bulk density. A numerical scheme, essentially similar to that of Quadri *et al.* (1994), was used to simulate the progression of the wetfront. We consider the water content of the wetfront to be θ_{wf}=0.15 m^3 per 1 m^3 bulk soil.

RESULTS AND DISCUSSION

The spatial pattern of the wetting, shown in Fig. (2), was used to plot the growth of R, Z and R^2Z in Fig. 3. Along with these traces are plotted the simulated curves for the growth in R and Z. It can be seen that the ellipsoid describing this pattern goes from being oblate, at early times, through to being spheroidal by about the end of the experiment. It would eventually become prolate, with further extension being limited to the vertical. The plot of R^2Z data is indeed linear with time which justifies this simple ellipsoidal description using some temporally-constant, average water content θ_m. The regression slope of the growth rate of the ellipsoid, $d(R^2Z)/dt$, is 3150 mm^3 s^{-1}: since q_∞=1131 mm^3 s^{-1}, then the appropriate-average water content difference ($\Delta\theta=\theta_m-\theta_n$) over the wetted ellipsoid is 0.171. This is just 62% of the Green & Ampt model, *viz.* full wetting to $\theta_o-\theta_n$=0.275. We can also compute $\Delta\theta$ directly from V (Eq. 3), which now includes some impact of the short-time, capillary-dominated flow. At the end of the experiment, after 585 s, V=7.15x10^5 mm^3, so $\Delta\theta$=0.184, whereas our numerical model found V=6.51x10^5 mm^3, hence $\Delta\theta$=0.191. The 3-D nature of the flow "flattens" the wetting profile, as theory predicts, and both our measurements and simulations show. (The experimental data in Fig. 4 show the flat profile. The profile is flatter in 3-D flow than 1-D flow, because the water is being pulled laterally by capillarity as well as vertically by capillarity and gravity.) So the ratio $\Delta\theta/(\theta_o-\theta_n)$, here 65-70%, is less than that prevailing during 1-D flow. For gravity-free 1-D absorption in this soil, our numerical model finds this ratio is about 85%, whereas during 1-D vertical flow with gravity it is about 92% - virtually the full Green and Ampt case, which applies to 1-D flow (Fig. 4, horizontal and vertical profiles, respectively). Hence under a disc, the average water content of the wetted ellipsoid is, as expected, much lower than that for 1-D flow in the soil. In addition to the experimental data and the Green and Ampt profiles, Fig. 4 shows the results of the numerical simulations for volumetric water content as a function of distance. Note that the simulations were done for 675 s, which is 90 s after the end of the experiment at 585 s (Fig. 2). In the simulations, we had to allow for the time taken to sample the soil for water contents. The time, 675 s, is about halfway through the sampling.

The parameters for the soil used in this experiment were varied in the numerical model to explore the effect of altering the soil's physical character on the shape of the wetfront. Wooding's (1968) equation was used to "back-out" values of the hydraulic conductivity, $K(\Psi_o)$, and sorptivity, $S(\Psi_o)$, when the flow, q(t), from the disc permeameter was steady, i.e., $q = q_\infty$. For example, in one simulation, the flow from the disc remained the same as above, but the hydraulic conductivity, K_o, was increased by 2.5 times, and the sorptivity, S_o, consequently dropped to 55% of its original value. The wetfront then extended deeper, but its breadth was less.

These Wooding parameters obtained by the disc permeameter can be used in a "forward" sense to predict the pattern of soil wetting during any flow regime - rain, drip, spray, or flood. However, as noted above, profiles predicted from Wooding's equation hold only at infinite time and, thus, they cannot give any information about transient wetfronts. Where the ellipsoidal idea has merit over Wooding's equation is in the practical operation of the disc permeameter. The ellipsoidal equation can give answers to the following questions: How deep is the wetfront at any time? By what means can it be reckoned simply? Also, we can answer other questions relating to the *modus operandi* of the disc permeameter. How much of the soil's volume has been wetted during a disc experiment? What volume of soil has been sampled, and hence to what depth of soil do the Wooding K and S values apply? For example, is it the top 20 mm, or 200 mm, that the disc has wet? Do Wooding's K and S refer to the surface layer, or some amalgam with the underlying soil? Answers are needed when using the disc permeameter to assess tillage effects, especially near the surface where tillage management is likely to have an important (yet maybe shallow) effect on soil properties. Using mass balance, in the ellipsoidal scheme, allows us to answer these questions in the field, just by observing the flow and the amount of water infiltrated. If the zone infiltrated is too deep, by our ellipsoidal calculations, then a platform can be excavated and a new measurement site can be created further down the profile on a ledge. Here then another measurement can be made, and the profile of K and S built up.

The disc permeameter might be practically applied, not only to different tillage situations, but also to different irrigation systems, including drip and furrow irrigation. Perhaps one could put the disc permeameter, set at a constant negative potential, on a dry soil and see how far water is sucked out to the side and calculate the volume wetted, based on the ellipsoidal equation. The distance could be measured with a ruler. Then one could place irrigation sources at distances apart, based on the measurements.

The ellipsoidal equation has another advantage: it is simple to use and people with essentially no mathematical training can apply it. A small hand-held calculator could be easily programmed to make the calculations.

CONCLUSION

Both laboratory experimentation and numerical simulation have been used to parameterise a simple ellipsoidal model of water flow under a disc. If an average wetting of about 65-70% of (θ_o-θ_n) is assumed, then dual observations of the surface wetfront and the volume infiltrated, allow simple prediction of the wetted depth. The sampling volume of the disc permeameter can thus be easily estimated, simply and quickly in the field. The equation that we developed, assuming an oblate ellipsoid shape for the wetting fronts, has predictive value. In the field, unlike the laboratory where we used a clear plastic box, we cannot view how far the water has advanced vertically into the soil. But we can see the distance that the horizontal front advances on the soil surface away from the source, and we can measure this distance with a ruler. From this ellipsoidal assessment of the depth of penetration, we can easily infer the depth of soil over which the disc permeameter has effectively provided a measure of the soil's physical properties. This could be used to ensure effective measurement of any stratification in the soil's physical character engendered by tillage.

ACKNOWLEDGEMENT

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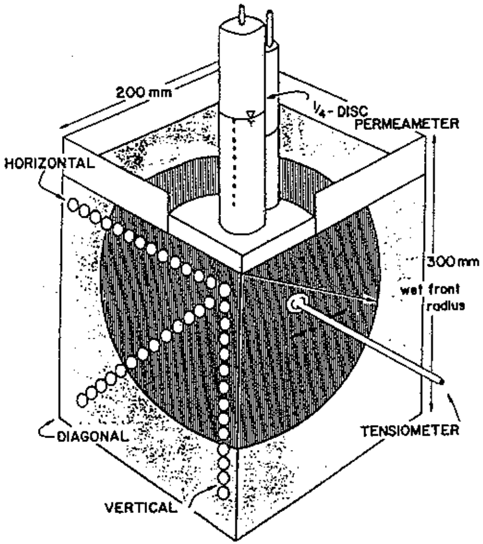

Fig. 1. Acrylic box in which the ¼-disc permeameter was placed upon repacked Manawatu fine sandy loam. Soil samples were extracted through the holes on the left-hand face. (From Quadri et al., 1994).

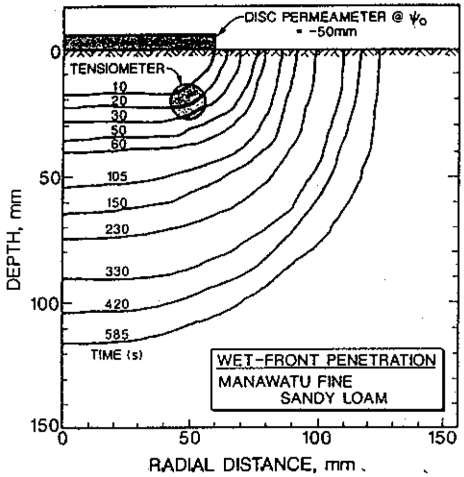

Fig. 2. Wetfronts.

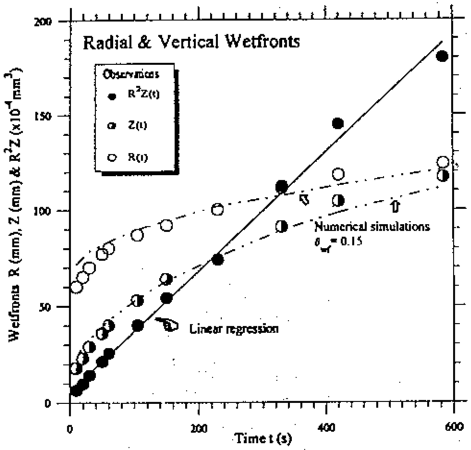

Fig. 3. Wetfronts and ellipsoidal $R^2 Z$

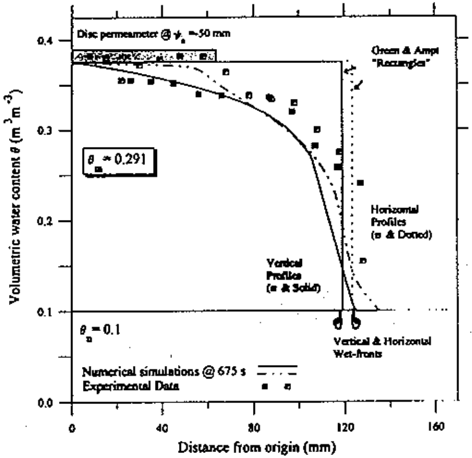

Fig. 4. Volumetric water content vs. distance for experimental data, numerical simulations, and Green and Ampt calculations.

MEASURING AND CALCULATING THE UNSATURATED HYDRAULIC CONDUCTIVITY - TECHNICAL REQUIREMENTS AND MEASURING ACCURACY -

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ABSTRACT

The paper deals with the development and the test of an automatic equipment of the evaporation method (1) to quantify the unsaturated hydraulic conductivity and the water retention curve.

The measuring accuracy was increased by using micro tensiometers with both relative and difference pressure transducers and a high sensitive digital scales. The set-up was connected with a computer. The parameters and the test results of the equipment are presented.

The results show the higher accuracy of the measured unsaturated hydraulic conductivity function and the water retention curve in comparison with the former equipment. Quantifying hydraulic conductivity values in the range lower than 0.1 m/d is possible.

Additional comparisons between measured and calculated hydraulic conductivities were carried out for a sandy loam and a clayey loam using the model SHYPFIT (2). The measured and the predicted conductivities of these soils show a good coincidence in the gradient and in the course of the function.

INTRODUCTION

The unsaturated hydraulic conductivity (k_u-function) and the water retention curve (WRC) are important hydrological parameters to characterize the water balance and to quantify the transport and storage properties of soils. Because of the increasing use of simulation models there is a necessity for quantifying the soil hydraulic properties adequately in a routine examination.

The evaporation method (1) allows easy to measure both the k_u-function and the WRC. In the standard equipment tensiometers with mercury gauges are used. The accuracy of the pressure measurement is approximately 200 Pa. That means high standard deviations in the lower range of suction. Because of such an insufficient measuring accuracy it is impossible to quantify reliable hydraulic conductivity values higher than 0.01 m/d. A further disadvantage of the standard equipment is the indispensable presence of a supervising person for every day. Therefore the aim was to automate the evaporation procedure and to develop an on-line combined equipment with a higher measuring accuracy.

Apart from measuring the hydraulic conductivity in field or laboratory experiments, it is a common way to predict the k_u-function based on a functional description of the WRC. Several different methods are known and used for measuring the water retention curve and quantifying the hydraulic conductivity (3). The commonly used approaches for describing the WRC and predicting the k_u-function are the Van Genuchten equation (4) and Mualem's partial correlated pore model (5). The model SHYPFIT (2) was used to predict the k_u-function of different soils on the basis of the WRC and to compare it with the measured conductivities.

MATERIALS AND METHODS

Measuring the hydraulic conductivity

A 250 cm³, 6 cm high cylindric core sample was saturated. Laterally two tensiometers were installed at a distance of $\Delta z = 3$ cm to determine the suction. The sample was sealed at the bottom and put on a scales. The core surface was exposed to free evaporation, and the weight loss was measured in relevant time intervals. The hydraulic gradient was derived from the values of suction. Based on the assumption of a linear water distribution in the sample the volumetric flow was calculated from the weight difference. The validity of this assumption was tested and confirmed for different soils (6). The hydraulic conductivity was calculated according to Darcy's law. The measured values were also used to determine the water retention curve.

Figure 1 shows a measured water retention curve and k_u-function using the standard set-up. The typical gaps in the WRC and the deviations in the k_u-function are visible.

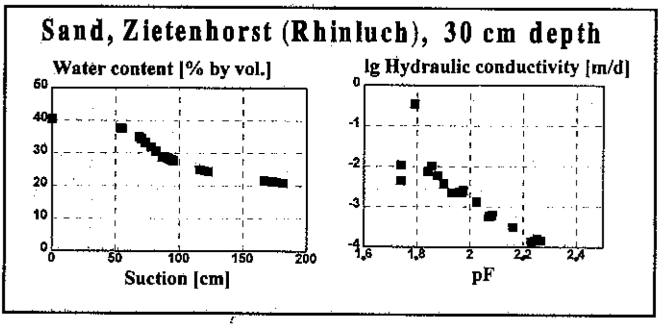

Figure 1: Measured water retention function and hydraulic conductivity values of a sandy soil using the former standard set-up of the evaporation method

To get an acceptable k_u-function high requirements concerning the measuring accuracy exist especially in the lower range of suction. Approximately 3 to 4 Vol.-% of water evaporate every day. These conditions require a measuring accuracy in the suction difference between the lower and upper levels of the sample of less than 10 Pa for quantifying hydraulic conductivities of about 0.1 m/d. The higher the measuring accuracy of the difference pressure measurement, the higher the quantified range of the unsaturated hydraulic conductivity function. With increasing suction and decreasing conductivity, respectively, the requirements to the measuring quality decrease.

The following requirements have to be kept:

1. Measuring accuracy: suction	< 10 Pa	in the suction range < 10 kPa
	100 Pa	in the suction range > 10 kPa
weight	0.01g	

2. Continuous measurement with variable measuring intervals according to the evaporation process.

Predicting the hydraulic conductivity

The model SHYPFIT (2) was used to predict the k_u-function for a sandy loam and a clayey loam. It allows uni- as well as multi-modal fitting of the water retention curve and the prediction of the k_u-function based on it.

The fitting of the water retention curves was carried out using both procedures. The best approximation was used considering the duration of the fitting procedure.
To estimate the quality of the k_u-prediction comparisons between the measured and the predicted k_u-functions were carried out. This was possible by transformation of the predicted function to the measured level using measured k-values as "matching" transformation points.

RESULTS AND DISCUSSION

Automated evaporation method

Figure 2 gives a schematic impression of the equipment. The measuring apparature is connected with a personal computer. The used configuration and software ensure the registration and storage of the measured data and allow the control of the measuring procedure.

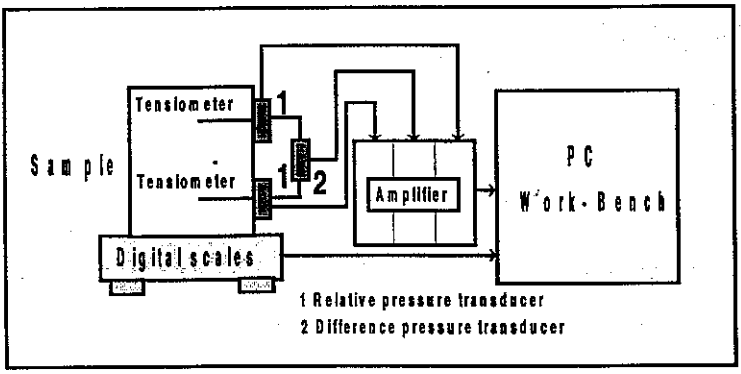

Figure 2: Principle of the automated evaporation method

The number of the tensiometers as compared with the standard equipment is not increased, but the measuring accuracy of the tensiometers is improved. The suction measurement is carried out with micro tensiometers. Two relative pressure transducers and, additionally a high sensitive difference pressure transducer are used. The measuring quality of the relative pressure transducers is sufficient in the higher range of suction (> 10 kPa). The used difference pressure transducer ensures also a high measuring accuracy in the lower range of suction and permits quantifying reliable hydraulic conductivity values of approximately 0.1 m/d. The accuracy of the weighing procedure of 0.01g is sufficient.
There is no need for supervising the automated measuring procedure so that the whole course of the k_u-function and also the WRC are recorded continuously over the measured range (Figure 3). The parameters of the used instruments are summarized in Table 1.

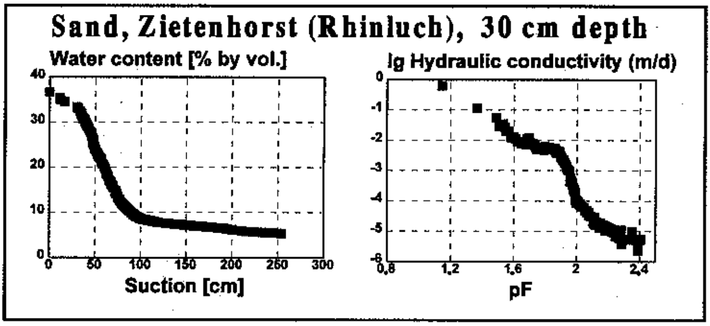

Figure 3: Water retention curve and unsaturated hydraulic conductivity of a sandy soil as measured with the automated evaporation method

Table 1: Technical parameters of the automated equipment

Instrument/Parameter	Values
- Digital scales	0.01 g (during continuous load)
- Tensiometer cup	
Diameter	1.4 mm
Length	45 mm
Wall thickness	0.3 mm
Reaction time after Richards	23 to 43 s
Bubble point	> 70 kPa
- Relative pressure transducer	
Measuring range	0 to +/- 100 kPa
Accuracy	100 Pa
- Difference pressure transducer	
Measuring range	0 to +/- 3.5 kPa
Accuracy	5 Pa
Linearity	6.9 kPa (over the whole range)
Burst pressure	128 kPa
- Measuring interval	30 min to 4 h (depending on the process)

Comparison between measured and predicted hydraulic conductivity functions

Figure 4 shows that the coincidence between the measured and the predicted course of the k_u-function is good. In the example presented here, the uni-modal fitting of the WRC was sufficient. However, bi-modal or multi-modal fitting procedures provide better results in many cases (2,7).

In using SHYPFIT or similar procedures must be considered that only the relative hydraulic conductivity will be predicted based on the fitted WRC. In Fig. 4 relative hydraulic conductivity values were transformed in absolute values using a single transformation point.

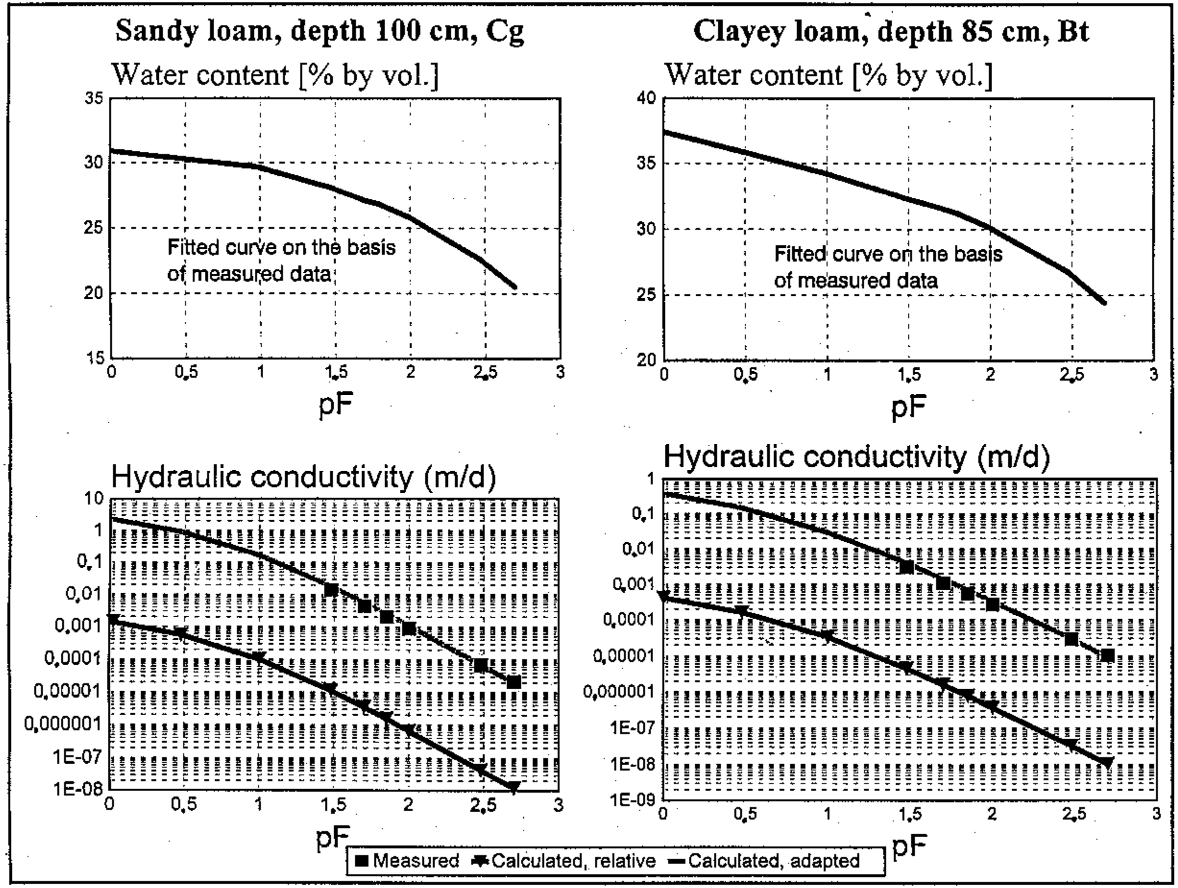

Figure 4: Comparison between measured and calculated hydraulic conductivity functions, (Bölkendorf site)

CONCLUSIONS

The automated equipment of the evaporation method permits the quantification of reliable hydraulic conductivity values < 0.1 m/d. Knowlegde of this range of hydraulic conductivities is very important for water transport processes in the soil, such as the capillary water rise.

With the presented set-up, the evaporation conditions during the measurement are not controlled. However, the results could be improved by controlling the thermic and air moisture conditions in the measuring box or room. Further improvement will be possible by additional installation of a sample changer and a user-communicated software.

The comparison between the measured and predicted hydraulic conductivities demonstrates a good coincidence in the gradient and in the course of the k_u-function. However, if measured conductivities will be available not at all, the main difficulty of predicting hydraulic conductivity functions is the determination of the matching point for transforming predicted relative in absolute k_u-values. The estimation of the matching point needs further research.

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VANE SHEAR STRENGTH OF A SALTMARSH SOIL: SPATIAL AND TEMPORAL VARIABILITY AND EFFECT OF GRAZING

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ABSTRACT

The spatial and temporal variability of vane shear strength of a seaside saltmarsh soil in Schleswig-Holstein, Germany, was measured with a field vane shear apparatus to determine its seasonal and spatial variability and the effect of sheep grazing. The results show that the vane shear strength of the transects was spatially dependent on the artificially laid drainage system and varied seawards from the dike in a cyclic pattern with a wave length of 100 m. Bulk density and water content of the transects varied in the same cyclic pattern too. However, no close correlation between soil strength and bulk density or water content could be found, indicating the complex relation between them. Seasonal variability corresponded with growth of plant roots and soil moisture conditions. Vane shear strength of soil firstly increased with grazing intensity and reached a maximum at about 1.0 SE/ha. Higher grazing intensity caused no further increment in soil strength. It is concluded that drainage promotes the consolidation and stabilization of the saltmarsh if combined with extensive grazing. However, grazing intensity should not exceed 1.5 SE/ha. Higher intensity increases the risk of structure deterioration resulting from compaction and poaching.

INTRODUCTION

Soil strength of saltmarshes is at least of twofold importance. First, saltmarshes are often suggested to function as a barrier for buffering the wave energy and for protection of the dike. Soil strength is a crucial parameter for evaluating the erosion resistance of saltmarshes against hydrodynamic impact. Secondly, saltmarshes are used frequently as seasonal grazing land. Soil strength can be used hereby as parameter to evaluate the suitability of saltmarshes for grazing, since poaching can occur if soil is not strong enough to support stress exerted by the grazing animals.

There are about 6500 ha seaside saltmarshes in Schleswig-Holstein and about 93% of it are used traditionally as seasonal grazing land (Anonymous. 1992). This kind of land use was considered to meet both the agricultural and coastal protection demands harmoniously, assuming that the trampling strengthens soil and enhances the soil stability, so that the function of saltmarshs as a buffering barrier can be guaranted. However, this grazing system is increasingly critisized by ecologists because it represents an artificial interference into this natural environment, affecting the development of this particular ecosystem and even endandering a number of species (Heydemann, 1984). From an ecological point of view, 70% of the seaside saltmarshes in Schleswig-Holstein are stressed due to overgrazing and extensive drainage (Anonymous, 1992). However, an abandonment would alter not only flora and fauna of this area but also the soil properties such as shear strength that is of large significance for the coastal protection.

The objective of this study is therefore to investigate the spatial and temporal variability of the vane shear strength of a saltmarsh soil in relation to the effect of grazing. Moreover, indications for the development of a saltmarsh management concept combining the environmental and agricultural as well as coastal engineering demands, are to be deduced from this study.

MATERIALS AND METHODS

The study site is located in a seaside saltmarsh in Sönke-Nissen-Koog, Schleswig-Holstein, North Germany. Since 1988 the authority of the National Park Wadden Sea of Schleswig Holstein established in this area grazing experimental plots with grazing intensity of 0.0, 0.5, 1.0, 1.5 and 3.4 SE/ha. The grazing intensity was defined as sheep unit per hectar (German abbreviation SE/ha), a sheep unit including a ewe, 1.5 lambs and 0.3 "Zutreter". The width of the seaside saltmarsh ist about 1 km, 700 to 900 m of it are accessible for the sheep. Until now no data are available about the accretion of the studied site. However, Heydemann (1984) suggested an average vertical accretion of 10 mm and a seaward extension of 10 m pro year along the Schleswig-Holstein coastline. Because of the young age and relative small width no apparent zonation of vegetation has developed so far. It consists mainly of *puccinellia maritima* and *salicornia europae* in the grazed plots. In the nongrazed plot, however, there is a great diversity of species such as *aster tripolium*, *artemisia maritima*, *puccinellia maritima* and *suaeda maritima*. The saltmarsh is regularly flooded more than 100 times per year. A 10 × 100 m drainage grid, consisting of the seaward minor ditchs of 100 m length and perpendicular main ditchs, divides the area into 10 × 100 m beds.

The soil is a silty loam with about 70% silt (2-63 μm), < 10% sand (63-200 μm) and about 20% clay (< 2 μm). There were hardly found any coarse particles > 200 μm in the mechanical anaylsis. Apparently controlled by the sedimentation, the clay fraction started near the dike at > 30% and decliened seawards down to < 10% while the sand fraction (mainly fine sand) increased seawards from < 10% up to > 50%. The soil contains about 2% organic carbon and 4% carbonate and has a pH value ($CaCl_2$) of 7.6 to 7.8 and a bulk density of about 1.0 Mg/m^3. The saturated conductivity is of an order of 10^{-4} cm/sec. The salt content of the soil fluctuates between 1 and 5%, depending on the weather conditions and flooding events.

The soil strength *in situ* was measured using the commercially available H-60 field inspection vane shear tester (Geonor, Norway) It consisted of exchangeable vanes, 0.5 m extending rods and a torque recorder with hand grip. A 16 × 32 mm vane was used in this study which enables the measurement of the peak shear strength of 0-400 kPa.

The vane shear strength was sampled at about 25 mm soil depth (vane centre) in the plots with varying grazing intensity two-weekly throughout the year 1993. For the investigation of the spatial variability and the effect of grazing, the vane shear strength was sampled every 5 m along transects across the grazing experimental plots in Oktober 1993. At the same time, core samples of 56 mm diameter by 40 mm height were taken at 0-50 mm depth along the transects at the same distance interval of 5 m to determine the spatial distribution of bulk density and water content (Blake and Hartge, 1986).

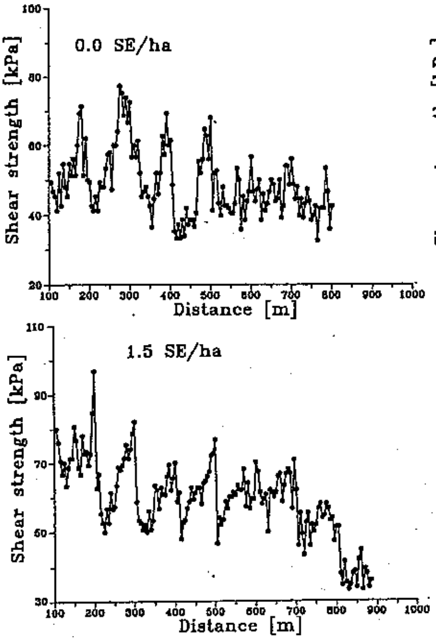

Abb. 1: Spatial distribution of the vane shear strength along transects of the experimental plots with varying grazing intensity

RESULTS AND DISCUSSION

Spatial Variability

Vane shear strength along the transects are illustrated in Fig. 1. It appears that in all of the transects the vane shear strength varies in a cyclic pattern with a wave length about 100 m which corresponds to the length of the beds. Furthermore, it can be observed that the vane shear strength is the lowest at the beginning of the bed and the highest at the end of the bed. Apparently, this is a result of the artificial drainage system. As described in the prior section, the minor ditchs at right angle to the dike are shallow at the beginning of the beds, deepening seawards and discharge into the main ditch at the end of the beds. The completion of drainage increased gradually seawards towards the main ditch and it is at highest at the end of the beds. More extensive drainage results in a better consolidation of the soil due to desication (Allen and Pye, 1991). It is also asserted by the data of the bulk density which varies in a similar cyclic pattern as the vane shear strength (Zhang and Horn, unpublished). However, the correlations between vane shear strength and bulk density (Tab.1) indicates that the soil strength is not merely affected by the bulk density. It is most likely determined also by root strength, root density as well as soil-water potential.

The mechanisms governing the development of soil strength of saltmarshes, are of complex nature. Not only the internal factors such as texture, mineral composition, organic matter content and soil structure are important, but also the external factors such as water content/potential, vegetation and compaction (Horn, 1988). A distinct relation between soil strength and bulk density or water content is found only when the texture of soil is similar

Tab. 1: Simple correlation coefficients between vane shear strength τ, bulk density ρ_b and water content θ of the transects in the plots with varying grazing intensity

Transect	τ vs. ρ_b	τ vs. θ	ρ_b vs. θ
0.0 SE/ha	– 0.166	+ 0.017	– 0.946***
1.0 SE/ha	+ 0.106	– 0.203*	– 0.958***
1.5 SE/ha	+ 0.133	– 0.217*	– 0.956***
3.4 SE/ha	– 0.184*	+ 0.072	– 0.974***

Tab. 2: Summary statistics of the vane shear strength, bulk density and water content along transects of plots with 0.0, 1.0 and 3.4 SE/ha grazing intensity

Transect	n	Median	Mean	SD	CV	Min.	Max.	Skewness
Vane shear strength, τ (kPa)								
0.0 SE/ha	140	47.3	49.0	10.5	0.21	32.7	77.3	0.83
1.0 SE/ha	120	60.3	61.8	12.7	0.20	30.7	88.7	– 0.09
1.5 SE/ha	160	59.7	58.7	12.1	0.20	26.7	96.7	– 0.36
3.4 SE/ha	180	66.3	64.5	12.5	0.19	26.7	90.7	– 0.65
Bulk density, ρ_b (Mg/m^3)								
0.0 SE/ha	150	0.91	0.95	0.17	0.18	0.60	1.35	0.47
1.0 SE/ha	120	0.94	0.94	0.14	0.15	0.66	1.31	0.25
1.5 SE/ha	120	0.92	0.96	0.13	0.14	0.69	1.33	0.90
3.4 SE/ha	160	0.99	1.00	0.14	0.14	0.72	1.45	0.22
Water content, θ (w/w%)								
0.0 SE/ha	150	60.6	60.6	17.2	0.28	31.0	118.0	0.43
1.0 SE/ha	120	60.6	61.9	16.2	0.26	28.1	104.8	0.36
1.5 SE/ha	120	61.2	59.4	12.6	0.21	24.5	101.3	– 0.16
3.4 SE/ha	160	53.8	55.3	13.1	0.23	17.1	84.0	0.21

(Douglas, 1986). Therefore, it is more an exception than a rule to find close correlations between them in saltmarsh soils because of their well-known heterogeneous textures. To identify the effect of grazing on soil compaction and strength of the saltmarshes, it would be more suitable using a parameter which characterizes the relative consolidation of soil e.g. the Håkanssons's degree of compactness (Håkanssons, 1973) than bulk density.

The summary statistics of the vane shear strength, bulk density and water content of the transects are presented in Tab.2. The coefficient of skewness shows that the data are approximately normally distributed. The vane shear strength and the bulk density of grazed plots are signficant different from those of the nongrazed plot ($P<0.01$). Among the different intensities of grazing no significant difference can be preceived ($P<0.05$). The water content decreased with increasing grazing intensity. The coefficient of variation CV indicated that grazing reduces the variation of the measured soil properties.

Temporal Variability

Fig.2 depicts the temporal variability of vane shear strength in the plots with different grazing intensity. The strength began to increase at the beginning of May which could be a result of root growth and temporal desication during spring time. In June soil strength

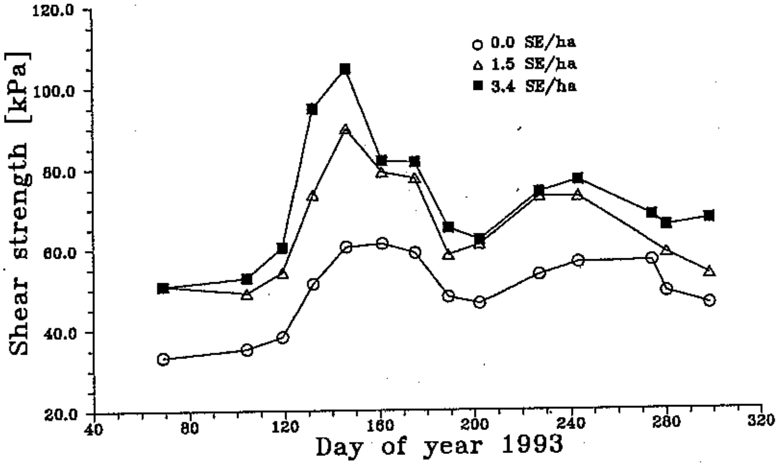

Abb. 2: Temporal variability of the vane shear strength of soil in the experimental plots with 0.0, 1.0, und 3.4 SE/ha grazing intensity

reached a maximum and decreased afterwards. This can be a result of rainfall and partly trampling effect on the grazed plots. The soil strength recovered only slightly in the following time and declined again at the beginning of October. It appeared that the plant root growth and the moisture conditions are the most important factors controlling the temporal variability of vane sbear strength.

Effect of Grazing

The effect of grazing on the vane shear strength of the saltmarsh soil is illustrated in Fig. 3. The vane shear strength rised with increasing grazing intensity and reached a maximum at a intensity of about 1.0 to 1.5 SE/ha. The higher intensity of 3.4 SE/ba did not cause significant ($P<0.05$) increase in soil strength . This is probably a result of increasing structure deterioration due to trampling. Grazing means on one side soil compaction that increase soil strength, on the other side also poaching, especially under the unfavourable moisture conditions in the saltmarsh, that causes structure deterioration and reduces soil strength.

In Fig. 3 (right) the vane shear strength is also plotted against the distance from the dike for the experimental plots. Each point represents the average value of 21 samplings taken in a bed in March 1993. It is obvious that the increase of soil strength is more marked near tbe dike and reduced with the rising distance from the dike. This can be explained by the grazing frequency because the sheep prefer to stay close to the dike.

CONCLUSION

The vane shear strengtb of the saltmarsh soil varied spatially in a cyclic pattern across the grazing experimental plots with a wave length of 100 m. This spatial variation pattern is constrained by the artificial drainage system. Althougth bulk density and water content varied in the same pattern, no close correlation between shear strength and bulk density or water content could be found. It is necessary to take into accout the variation of soil texture when analysing causal relations between them. Grazing enhanced the vane shear

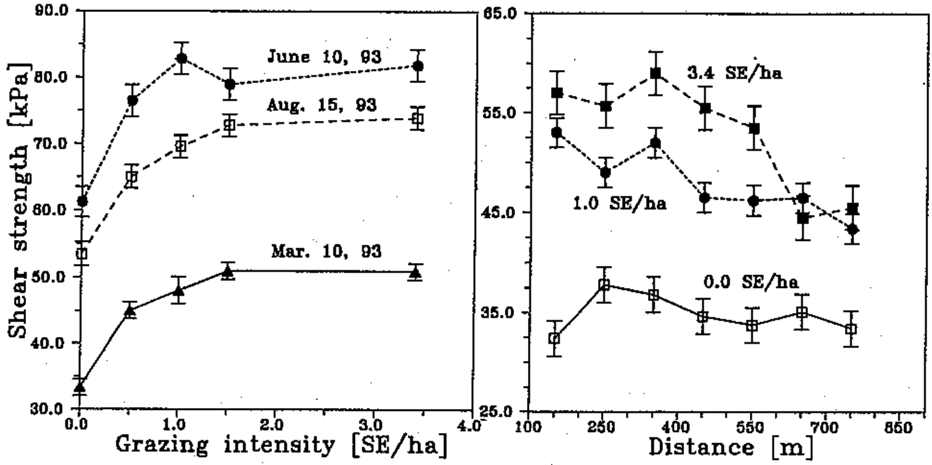

Abb. 3: The vane shear strength of the saltmarsh soil as related to the sampling time, the distance from the dike and the grazing intensity

strength of the soil near the dike more intensely because the sheep prefer to graze in this area. Seasonal variability appeared to correspond to the plant root growth and soil water status and is hardly affected by grazing. The variation of the measured soil properties seemed to be reduced by grazing as shown by the coefficients of variation.

For the management of the saltmarshes a grazing intensity of about 1.0 to 1.5 SE/ha can be recommended. Higher intensity causes no more significant increase in soil strength, but involves a higher risk of poaching and structure deterioration. Drainage is advantageous for the consolidation and stabilization of the saltmarsh soils.

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Three-dimensional stress and strain distribution in a loamy sand due to wheeling with different slip

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Abstract

The stress distribution in soils always requires the simultaneous determination of the 6 stress components (3 principal and the 3 not rectangular stresses) in order to solve the stress equation. Furthermore, the stress affected strain also consists of 6 components which have also to be determined.
The higher the slip percentage, the smaller becomes the vertical principal stress and the more pronounced are the horizontal principal stresses i.e. the tensile stresses. Repeated wheeling results in a more pronounced development of such behaviour. At high slip percentage and repeated loading the mean normal stresses are reduced while the octahedral shear stresses are identical. Thus, the shear strength will be exceeded and a further deformation occurs. This can be verified by the kind and intensity of particle displacement. At small slip a positive displacement occurs (i.e. the particles will be pushed ahead of the wheel) while at high slip percentage a backward displacement could be quantified. The distances from the centre line varied between +8 mm (low slip) and -65 mm (high slip) after 2 wheeling events. Theoretical explanations will be given.

Introduction

Due to the development of heavier agricultural machinery and due to the intensification of wheeling throughout the year the question about the maximum acceptable soil compressibility including soil deformation will be more often discussed (Soane and van Ouwerkerk 1994). However, soil deformation due to dynamic loading (i.e. by including slip as a main factor) can not only be discussed with respect to an increase in bulk density, but it has also to include the homogenisation of the soil volume and by that the changes in the pore geometry and continuity rather than only the total amount (Horn et al.1994). Each dynamic loading induces a mobilsation of internal shear resistances. As soon as the external octahedral shear stress exceeds the internal strength values at a given normal stress a further volumetric soil deformation including a soil homogenisation may occur. Thus, besides the three-dimensional stress also the volumetric strain pattern has to be determined, if the three-dimensional stress induced soil deformation should be analysed and quantified. Kühner and Horn (1994) developed a 2-dimensional displacement sensor, which enables the determination of the corresponding soil displacement during wheeling at different stress, slip or speed of wheeling in structured undisturbed soils. How far the slip also affects the kind and direction of deformation will be described and explained in the following.

Material and Methods

The wheeling experiments were carried out in a soil bin of the NSDL in Auburn/Alabma,USA. The soil material was Norfolk loamy sand which was completely homogenized and recompacted to a bulk density value of 1.38 (g/cm^3). The stress strain sensor was buried in a depth of 10 cm and the soil volume backfilled. Two wheeling events were performed by the well described wheel test machinery at two slip rates: 5 % (described as low) and 25% (=high). The water content during wheeling was 7.3% (by weight) throughout the whole soil bin. During the tests, the 6 stress components as well as the lateral and vertical soil displacements were recorded simultanously with a frequency of 30 per second. The 3 principal as well as the mean normal and octahedral shear stress components were calculated for the different wheeling experiments.

Results and discussion

Fig.1 informs about the highest principal (S1) and both rectangualar stresses (S2 and S3) for the two slip rates and the two wheeling events. It can be shown, that with increasing slip the stress s1, which direction is mainly near to that of the vertical stress, declines while the horizontal components increase. The more often the soil is wheeled, the more pronounced are especially the changes of the values for the horizontal components.

Furthermore, the values of the mean normal and the octahedral shear stress reveal an intensive change of the internal soil structure (Fig.2).

While during the first wheeling event both parameters only differ to a small extent, the second wheeling resulted in a decline in the mean normal stress value at high slip percentage while the octahedral shear stress value remains constant. Thus, it can be expected, that the stress dependent shear strength defined by the Mohr Coulomb failure line is exceeded and results in a further soil deformation.

Fig.3 informs about the measured 2 dimensional soil displacement during the wheeling experiments.

While the rut depth is nearly the same after 2 passages for both treatments, the pattern of the soil displacement as well as the direction reveal an intensive change between the two treatments. During the wheeling at low slip, the sensor will be displaced in direction of wheeling to a depth of about 70mm, whereby a minor backward displacement at a constant depth can also be verified. During the second wheeling event the sensor is further displaced to greater depth and also always ahead of the wheel i.e. as positive displacement. However, the additional rut depth formation is declined to 15% of the first one. On the contrary the wheeling experiments at high slip of approx. 25% reveal a rut depth formation of the same amount as with the low slip experiment but the sensor will be translocated by soil displacement backwards opposite to the wheeling direction. It can also be seen clearly, that at the end of the first wheeling the intensity of settlement became slightly reduced and at the end of the second wheeling even a small increase in height can be verified.

Summarising Disscusion

Each load applied at the soil surface always induces an increase in soil strength and only after exceeding the internal strength by the external forces the soil volume will be further deformed. The kind of stress changes due to wheeling at various slip and/or speed however can differ whereby they depend on the intensity of loading, number of loading events as well as on soil structure properties. In general, stresses are always transmitted threedimensionally, and the horizontal stresses quantify both, stresses and tensile strength values. The more intensive the soil has been compressed, the more intensive should the tensile strength values increase while kneading and homogenisation result in a more pronounced vertical stress component.

Consequently, also the soil deformation process can be subdivided into a volume constant process, a decrease in volume or an additional increase due to dilatation. The displacement of particles will be therefore always threedimensional even if the amount and proportion of each kind of deformation depends on the applied stresses, the kind of stresses and number of wheelings, whereby the more often the wheeling is carried out the more pronounced are the tensile strength values due to the former strength increase. Each previous deformation results in an increase in soil strength whereby the formation of a platy structure especially at high slip can be revealed by the greater negative horizontal stresses. Even if the amount of vertical strain i.e. the rut depth is therefore identical the processes and consequences for ecological soil properties can vary to a great extent.

It can be assumed that the pore size distribution is shifted to a more homogenous texture dependent pore system, while the pore continuity is reduced due to the homogenisation process induced by external stresses at various slip intensity.

Stress induced volumetric soil strain can therefore create a completely different internal soil structure formation or alteration of soil physical as well as chemical properties.

In the poster the data will be presented and the further discussion on consequences with respect to ecological parameters will be intensified.

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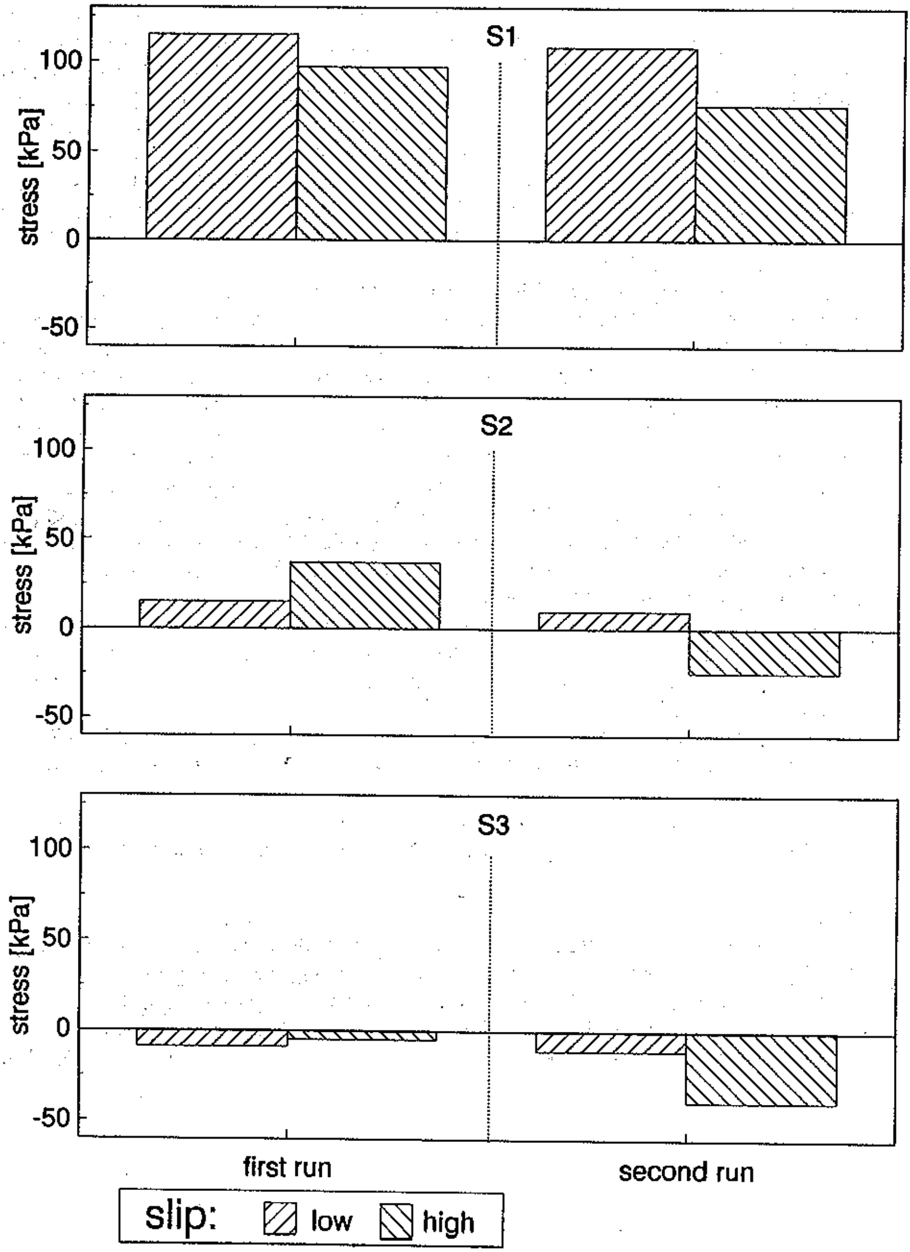


Fig.1: Changes in the 3 principal stresses (S1, S2 and S3) during wheeling with different slip percentage (5% = low; 25% = high)

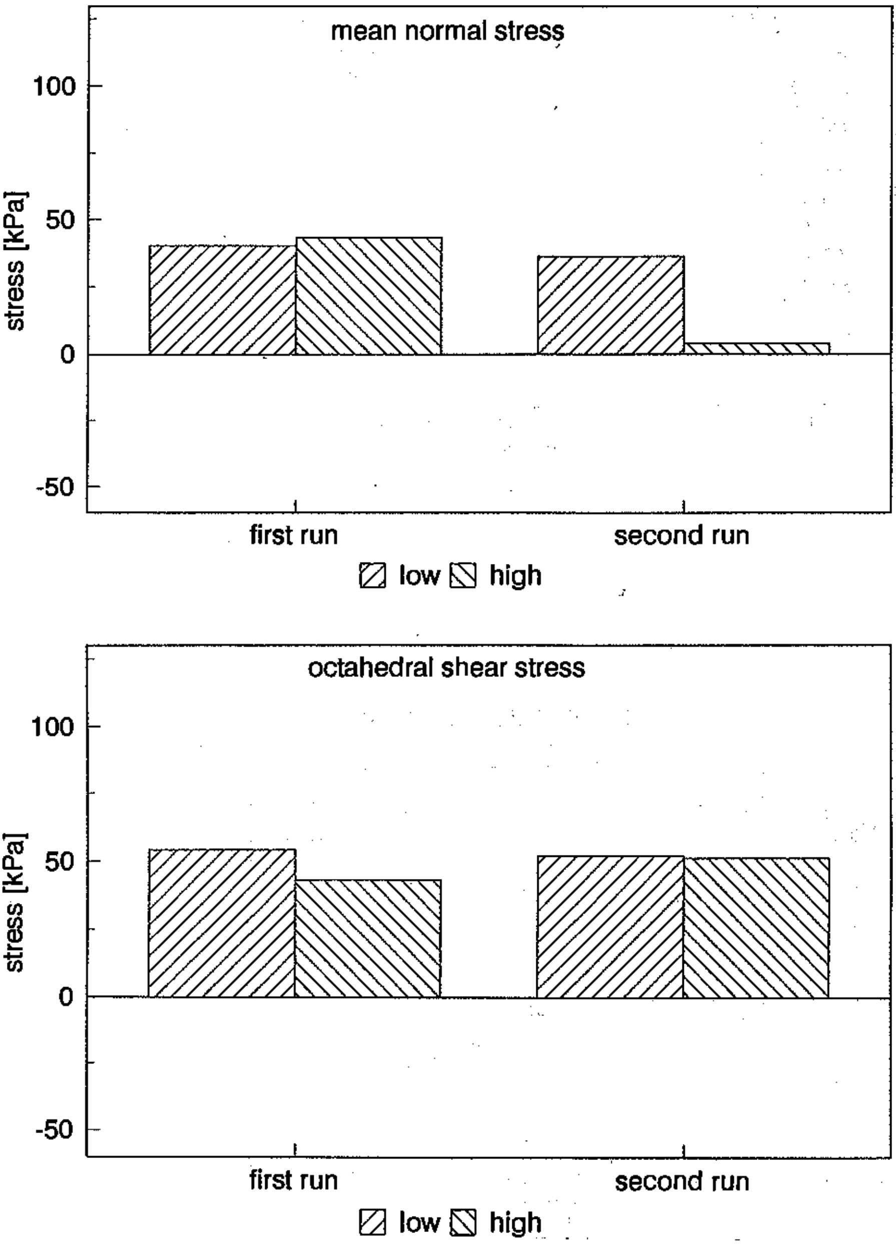
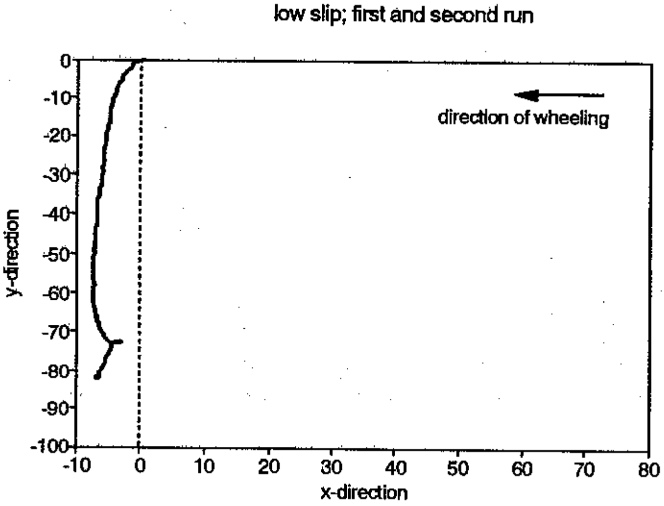


Fig.2: Changes in the octahedral shear stress OCTSS and the mean normal stress MNS during wheeling with different slip percentage (5% = low; 25% = high)



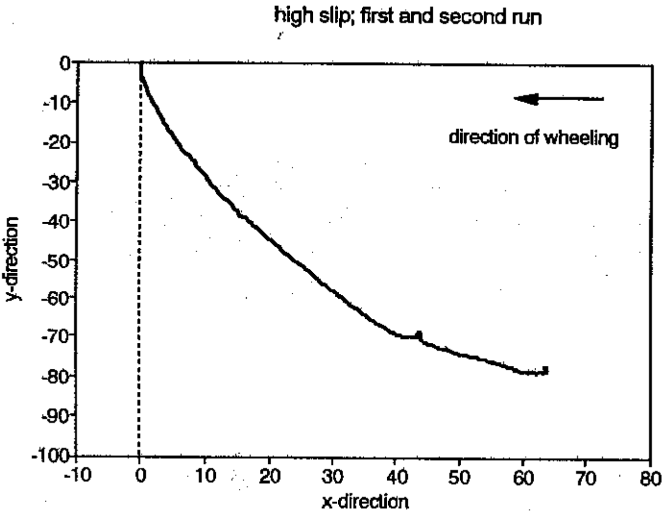


Fig.3: Two dimensional soil displacement affected by wheeling at different slip percentage and number of wheeling events.

MODELLING DISTORTION DURING SOIL COMPACTION FOR CYLINDRICAL STRESS LOAD PATHS

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ABSTRACT

A soil distortion model based on critical-state theory was formulated. Maximum shear strain was integrated numerically for cylindrical stress load paths with constant confining pressure (type I) or constant mean normal stress (type II) using previously specified parameters for two soils, each at three different moisture contents. Predicted stress-strain relationships were compared with stress-strain relationships observed in triaxial tests of the lubricated ends variety. The agreement between predicted and observed maximum shear strain depended on type of load path and soil moisture content. The model failed to predict maximum shear strain at stress states close to critical. The absolute difference between observed and predicted strain was on the average $\leq$ 0.05 for deviatoric stresses smaller than 90% of the critical-state values. The comparable maximum differences were 0.11 and 0.07 for load path type I and II, respectively. The largest differences were found for the largest soil moisture contents. The type of load path had considerable effect on sample distortion, type I giving rise to larger (predicted and observed) maximum shear strain at common stress states.

INTRODUCTION

The critical-state framework (Cam-clay theory) originally developed for saturated soil (Roscoe *et al.*, 1958) offers a theoretical basis for predicting not only the volume change behaviour, but also the shear deformation taking place during triaxial compression. Earlier studies based on triaxial compression tests on unsaturated soils (Bailey & Vandenberg, 1968; Leeson & Campbell, 1983; Hettiaratchi, 1987) and on the two particular soils considered in the present study (Petersen, 1993) have shown that the volume change behaviour is largely consistent with the critical-state concept, the role of soil moisture content being expressed in the values of estimated critical-state parameters. It was not attempted to calculate shear strain in the above mentioned studies.

The purpose of the present work was, by applying a critical-state model adapted to unsaturated soil conditions, to predict maximum shear strain, γ_{max} during compression of unsaturated soils for different cylindrical load paths and to evaluate the predictions with observations from triaxial tests.

The model

Different theories for the prediction of plastic strains in soil have been developed. The model to be described in the following is a modification of the so called modified Cam-clay model developed for saturated soils (Roscoe & Burland, 1968). Reviews of the critical-state and Cam-clay theory have been given by Atkinson & Bransby (1978) and Britto & Gunn (1987).

A short account of the critical-state theory including a discussion of the applicability to unsaturated soils was given by Hettiaratchi (1987). This section will concentrate on strain calculations during soil compaction. Stresses will be described in terms of total stresses applied at the soil boundaries. The normal sign convention that compressive stresses and strains are positive quantities will be used in all calculations.

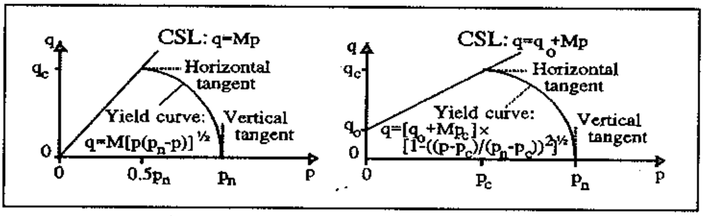

Figure 1. Compaction yield curve and critical state line (CSL) for modified Cam-clay (left) and for the proposed model for unsaturated soil (right). Mathematical expressions are included.

The modified Cam-clay model falls within the theory of hardening plasticity for materials which exhibit temperature- and time independent properties. The loading function for the model is assumed to be isotropic and consists of the following two parts: a state boundary for a perfectly plastic material and a yield surface which expands isotropically about the hydrostatic axis. The loading function for drained triaxial compression tests where $\sigma_2=\sigma_3$ can easily be represented on one plane. The state boundary corresponding to perfectly plastic behaviour is traditionally assumed to be a straight line (the critical-state line, CSL) passing through the origin of the co-ordinate system while the compaction yield curve is formed by a quarter of an ellipse (Fig. 1a). That part of the modified Cam-Clay theory which deals with strain softening behaviour is not included in Fig. 1 and will not be considered here. Three types of material response may now be represented: elastic (underneath the CSL and yield curve), perfectly plastic (on the CSL) and strain hardening (on the yield curve). The movement of the yield curve is controlled by the increase in plastic volumetric strain, $\delta\epsilon_{v,p}$ (see list of symbols) through a hardening law.

Experience with unsaturated soils (Hettiaratchi, 1987; Bailey & Johnson, 1988; Petersen, 1993) has shown that the CSL depending on structural state and soil moisture content may show a significant intercept, q_o on the q-axis. The existence of this intercept for unsaturated soil is very likely due to the formation of interparticle bridges and may be a direct consequence of describing the stresses in total rather than effective terms. On this experimental background, and because an accurate specification of the locus of the critical-state line projection on the p-q-plane is very important for the accuracy of especially large shear strain predictions (cf. Fig. 2), it is proposed that the loading function should be changed as shown in Fig. 1b. It is noted that the yield curve equation meets the required boundary conditions: $q=0$ for $p=p_n$, $q=q_c$ for $p=p_c$ and $dq/dp=0$ for $p=p_c$.

One of the key assumptions of Cam-clay theory is that the flow rule follows the normality condition, i.e. that the plastic strain increment vector, $(\delta\epsilon_{v,p},\delta\epsilon_{s,p})$ expressed with components that correspond to the stress vector (p,q) is always normal to the yield curve. Mathematically, the normality condition can be expressed as follows:

$$\delta\epsilon_{v,p}/\delta\epsilon_{s,p} = -\,dq/dp \tag{1}$$

where $\delta\epsilon_{s,p}$ is defined in the list of symbols. The other key assumption is that elastic shear strains are zero so that the specific volume anywhere on a yield curve can be derived as a function of mean normal pressure and the current p_n-value. Now, when for a state of stress (p,q) on the yield curve the gradient to the curve and the change of plastic volumetric strain $(\delta\epsilon_{v,p})$ corresponding to a small stress increment is known, the change of (plastic) shear strain, $\delta\epsilon_{s,p}$ (and maximum shear strain) is given by Equation (1). The relationships applied between mean normal stress and specific volume during hydrostatic compression, at critical states and during hydrostatic (elastic) unloading were the traditional critical-state equations. It is noted that the modified Cam-clay model prescribes a constant p_n/p_c-ratio = 2 whereas the p_n/p_c-ratio in the proposed model is a function of p_n. The locus of the yield curve is entirely fixed by p_n.

MATERIALS AND METHODS

The applied soils and methods of sample preparation have been described in details elsewhere (Petersen, 1993a). Briefly, a sandy loam from Tåstrup (soil T) and a loam from Mårum (soil M) were passed through a 2mm sieve, air dried and stored at constant air temperature and humidity. Reproducible, relatively loose samples (height: 80-83 mm; diameter: 83 mm) were formed after spoon feeding known amounts of soil into cylindrical formers, slowly wetting to zero soil moisture tension, and adjusting the tension separately for each series of experiments. The resulting average water contents were for soil T: θ = 95, 152 and 192 g kg^{-1} and for soil M: θ = 107, 141 and 195 g kg^{-1}. Sample dimensions were measured as a final part of the mounting procedure.

A triaxial test apparatus under computer control was used to apply continuously increasing stress levels following different preset loading sequences. The tests considered were all initiated by hydrostatic loading. From a normally consolidated state, samples were subjected to slowly increasing deviatoric stress maintaining either a constant confining pressure, $\sigma_2=\sigma_3$ (path I) or a constant mean normal stress, p (path II). The preset load paths were followed very closely. Thus, p deviated less than 1% from preset values at observed q values, generally. Shear loading was terminated when the soils reached or came near to a situation of shear at constant stress and volumetric strain, the criterion of critical state. The tests were conducted with lubricated ends and a 1:1 ratio of sample height to sample diameter as described by Head (1986, p. 1054) in order to accomplish uniform stress and strain states throughout the samples.

Sample length, confining pressure, axial force and changes in water content of the test chamber were measured using transducers. Stresses were corrected for changing contact area at the sample ends due to axial strain and to changes in sample volume as described by Head (1986, p. 890). Initial bulk density and specific volume, v_o was calculated from oven dry mass and initial sample dimensions, assuming cylindrical shape and a density of solids, ρ_S equal to 2650 kg m^{-3}. Specific volume, v was calculated from v_o and volume changes during the test. Changes in sample volume were derived from the volume of water moving into or out of the test chamber with corrections for expansion of the chamber with pressure increase and for displacement of water by movement of the loading ram as described by Head (1986, p. 900). Radial strain, ϵ_r was calculated from volumetric and axial strain assuming cylindrical dimensions and using the basic relationships shown in the list of symbols.

γ_{max} was calculated for 36 shear load paths identical to those applied in the triaxial tests. The calculations followed the general procedure described by Britto & Gunn (1987, p. 66) using critical-state parameters specifyed by Petersen (1993 a,b). Basically, the strain was calculated for a number of increments of stress once the sample had yielded.

RESULTS AND DISCUSSION

The model was evaluated by comparing observed and predicted γ_{max}-q relationships. Results for soil T at $\theta=152$ g kg^{-1} are shown in Fig. 2. The end points of observed relationships represent states first identified as being critical. Changes of stress and volumetric strain are zero or very small at this stage. However, γ_{max} increases very rapidly with q, so it will not be possible to attach a certain γ_{max} value to the critical state. Schoefield & Wroth (1967) regarded the critical state as pertaining to infinite strain and suggested that real samples never got there. γ_{max} values for incipient critical state predicted by the model (not shown) were always much larger than the observed values.

All the predicted γ_{max}-q curves originate from the origin. The close agreement between observed and predicted γ_{max} near the origin may be taken as a confirmation of nearly isotropic soil behaviour. For the hydrostatic loading sequences considered in this study γ_{max} values > 0.05 was found in three cases, only. The differences shown in Fig. 2 between observed and predicted γ_{max} were typical for most series of experiments (Petersen, 1993). The differences were most often positive during some parts of the load paths but almost always negative at a predicted γ_{max} value = 0.6.

The differences at common stress states between observed and predicted γ_{max}, $\Delta\gamma_{max}$ were calculated for all observed stress states with $q \leq 90\%$ of the observed and predicted critical-state value, q_{90}, this limit being chosen somewhat arbitrarily. Average $|\Delta\gamma_{max}|$ was always ≤ 0.051. The largest values were found for the wet soils. Maximum and minimum $\Delta\gamma_{max}$ were 0.111 and -0.072, respectively, both extremes being found for soil T at $\theta=192$ g kg^{-1} and both for $q=q_{90}$. For all the other series of experiments the comparable numbers were 0.079 and -0.068, respectively. Both the average $|\Delta\gamma_{max}|$ and the extreme $\Delta\gamma_{max}$ values were smaller for load path II than for load path I, generally, so the agreement between predicted and observed γ_{max} appears to be closer for load path II than I. Type of load path had a considerable effect on γ_{max}, type I giving rise to larger maximum shear strain at common stress states (Fig. 3). Thus, observed γ_{max} was larger for load path I than II for all common stress states except one (Fig. 3b) while predicted γ_{max} always was larger for path I (Fig. 3a). The effect of load path appears to be well represented by the model. Results indicating similar load-path effects were reported by Grisso *et al.* (1987).

$|\Delta\gamma_{max}|$ became normally very large for stress states close to the critical state. For the dry soils (soil T, $\theta=95$ g kg^{-1} and soil M, $\theta=107$ g kg^{-1}) the model systematically underestimated γ_{max} for $q \leq q_{90}$. Some relatively large $\Delta\gamma_{max}$ values were found, especially for the wet soils (soil T, $\theta=192$ g kg^{-1} and soil M, $\theta=195$ g kg^{-1}). Thus, the model proposed to describe soil distortion during triaxial compaction is obviously not perfect. One possible way to achieve better agreement between observed and predicted γ_{max} could be to use a fitted yield curve equation. However, the applied relatively simple critical-state model can describe important features of soil distortion, in particular effects of the two different load paths considered in the present study.

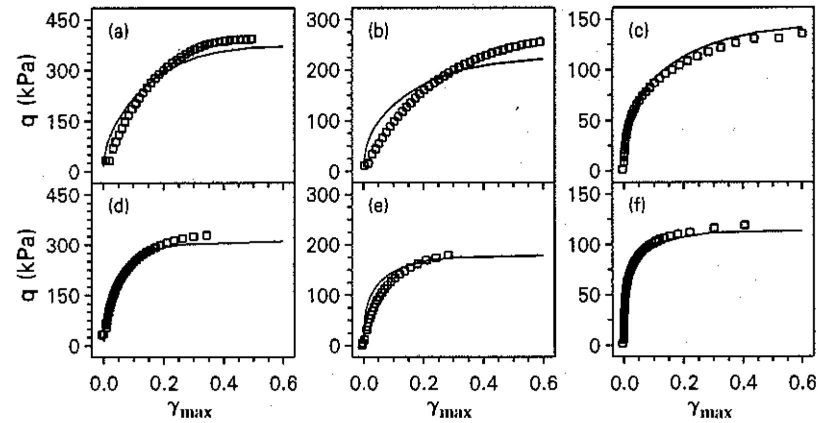

Figure 2. Observed (□) and predicted (——) γ_{max}-q-relationships for soil T at $\theta = 152$ g kg^{-1}. (a), (b) and (c): path I, initial p values: 125, 60.0 and 25.0 kPa, respectively. (d), (e) and (f): path II, initial p-values: 200, 100 and 50.0 kPa, respectively.

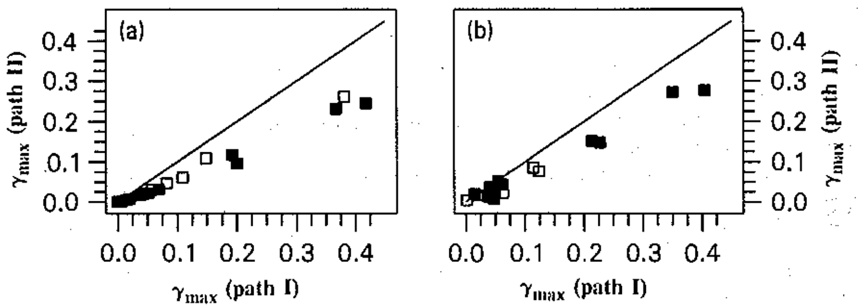

Figure 3. γ_{max} for load path II plotted versus γ_{max} for load path I at common stress states. Data for soil T (□) and soil M (■). (a): predicted relationship; (b): observed relationship. 45° reference lines are included.

CONCLUSIONS

The agreement between observed and predicted soil distortion dependeded on type of load path and on soil moisture content. The predictions of maximum shear strain differed from observed values on the average less than 0.051 for deviatoric stresses smaller than 90% of the critical-state values. The comparable maximum and minimum differences were 0.111 and -0.072, respectively. The largest differences were found for the largest water contents. The type of load path had considerable effect on sample distortion, type I giving rise to larger (predicted and observed) maximum shear strain at common stress states.

LIST OF SYMBOLS

σ_3, σ_2, σ_1	Principal (total) stresses applied at the soil boundaries.
q	$= \sigma_1 - \sigma_3$. Deviatoric stress.
q_{90}	Maximum deviatoric stress $\leq 90\%$ of expected and observed critical-state q value.
p	$= (\sigma_1+2\sigma_3)/3$. Mean normal stress.
p_n	Point on the normal consolidation line (NCL) used as hardening parameter. p_n represents the value of p at the intersection of the current yield curve with the p-axis.
(p_c, q_c)	Point representing the intersection of the current yield curve with the CSL.
ρ_s, ρ_b	Density of solids and dry bulk density, respectively.
v_o, v	($v=\rho_s/\rho_b$). Initial and current specific volume, respectively.
θ	Gravimetric soil moisture content.
ϵ_v	$= -(v-v_o)/v_o$. Volumetric strain.
δv	Increment of specific volume corresponding to stress increment (negative).
δv_e, δv_p	Elastic and plastic part of δv, respectively.
$\delta\epsilon_{v,e}$	$= -\delta v_e/v$. Elastic volumetric strain increment.
$\delta\epsilon_{v,p}$	$= -\delta v_p/v$. Plastic volumetric strain increment.
l_o, l	Initial and current sample length, respectively.
ϵ_a	$= -(l-l_o)/l_o$. Axial strain.
$\delta\epsilon_a$	$= -\delta l/l$. Axial strain increment.
r_o, r	Initial and current sample radius, respectively.
ϵ_r	$= -(r-r_o)/r_o = 1-[(1-\epsilon_v)/(1-\epsilon_a)]^{1/2}$. Radial strain.
$\delta\epsilon_r$	$= -\delta r/r$. Radial strain increment.
$\delta\epsilon_s$	$= \delta\epsilon_{s,p} \approx 2(\delta\epsilon_a-\delta\epsilon_r)/3$. (Plastic) shear strain increment.
γ_{max}	$= \epsilon_a-\epsilon_r$. Maximum shear strain.
$\Delta\gamma_{max}$	Difference between observed and predicted γ_{max}.

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LOADING DEVICE FOR LABORATORY TESTING OF LARGE SOIL SAMPLES

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ABSTRACT

The paper describes a loading device for testing of large soil samples brought into the laboratory from the field. The advantage with laboratory testing is the knowledge of and the increased control over the experimental environment. The disadvantage compared to field experiments is the difficulty in establishing the environmental conditions that exists in nature. However, for some types of experiments the difficulty of measuring the soil's response to loading counts in favour of laboratory tests. Thus it is, e.g., extremely difficult to measure the subsoil's reaction to stresses. Especially for the last reason the present testing device was designed and constructed.

The measuring method consists in obtaining large cylindrical samples of undisturbed soil. Sample size is 30 cm in diameter and 30 cm height. The samples are placed in the loading apparatus where a normal stress is applied to the top by means of a circular plate. Part of this plate consists of a shear ring which may be rotated through app. 170° while the normal load is maintained.

During the measuring process the sinkage of the loading plate, the sinkage of the shear ring during rotation, and the development of the shear stress are recorded. Because the normal stress is supplied by means of dead weight its magnitude is determined beforehand.

INTRODUCTION

Detrimental compaction of agricultural soil continues to be a problem in many places of the world (3). Especially the subsoil compaction is currently receiving much attention and the focus of the research appears to be shifting from studying the effect on crop growth towards the study of how stresses are transmitted through the soil profile and emphasize prevention of subsoil compaction (5).

Because soil is only to a certain degree a homogeneous material the distribution of stress in a soil mass can be estimated only approximately by theoretical analyses based on the laws of physics. There are nearly always stones and, perhaps, voids present with dimensions that are large compared to the volume of soil for which the stress field is being calculated. Similarly, the soil within the volume of interest is often stratified with different stress-strain relationships in the various strata. These conditions deteriorate the correctness of the results from the theoretical analyses.

On this background it is necessary to resort to - or, at least, incorporate - practical experiments. Such experiments may be divided into 2 groups based on the measured output, i.e., the results of the experiments. For both groups the experimental set-up incorporate some degree of loading of the soil. For the first group, however, the results are measured as the growth response of the crop whereas the results from the second group consist in more or less direct measurement of the physical changes of the soil itself. Although both types of experiments are necessary only the results from the second group may be used for validation of the theoretical analyses of the stress/strain relationship due to the extremely complex interactions between a plant's root system and the soil's condition.

In principle, field experiments are preferable due to the considerable difficulties in preparing soil samples in the laboratory so that they exactly match the desired field conditions. However, it is often very difficult to measure the response of relevant parameters to the experimental treatment in the field.

Especially when studying subsoil compaction these difficulties become evident. Thus, it is obviously impossible to install a measuring device in the subsoil without disturbing it and thereby change its stress/strain characteristics and, consequently, it local response to the experimental loading. Additionally, it is often difficult to achieve the required accuracy of the measuring results for field experiments. Especially for subsoil experiments because the measurable mechanical reaction of the subsoil is very little although its effect on root development may be considerable.

It was therefore decided to build a loading apparatus for soil samples. The samples are taken from the soil profile by means of a special machine described by (4). Because the loading device is placed in the laboratory it is reasonably easy to obtain measurements of the soil's mechanical reaction to an applied load with a relatively high degree of accuracy.

REQUIREMENTS

Prior to the construction of the device a number of requirements was set up concerning various details of the system.

The sample

The overall basic requirement of the soil sample when loaded in the laboratory is that it behaves just as it would do if it was in place in the field and was exposed to an identical loading. This is hardly possible to achieve totally but it should be the goal to come as close to as possible to this condition.

The first condition to be fulfilled in order to approach this goal is that the soil sample should be disturbed as little as possible by the sampling procedure, i.e., when physically obtained from the field. Generally, this calls for large samples and a cautious sampling procedure. The machine used to obtain the samples comes very close to these requirements as described by (4). The cylindrical soil sample is continually lined by a strong plastic tube during the drilling process and thus safely enclosed when finally obtained. The maximum working depth for the sampling machine is 1 m and the sample diameter is 30 cm. Thus, the sample height may anything between approximately 0.3 m up to 1 m depending on the dimensions of various equipment for the sampling machine. Likewise, intermediate soil samples may be obtained from, e.g., 0.5 to 0,8 m depth.

The apparatus

The primary task of the loading apparatus is to set up a certain stress field in the soil sample. I.e., the soil sample should ideally be acted upon in the same way as if it had never been taken. This is hardly fully possible but, even here, it serves as the goal that should be approached as much as possible.

Loading the soil

The stress field is accomplished by applying a combination of normal- and shearstress to the soil sample's surface. The stress-combination should be changeable as a function of time if desired.

The shear stress should be set up for only a part of the sample's surface in order to avoid complex stress fields at the outer cylindrical boundary of the samples. It is considered essential that the normal stress should be applied on all surfaces that surround the shearing surface as reported in (1). Furthermore, the normal stress should, of course, be maintained at the desired level on both shearing and non-shearing interfaces.

It should be possible to program the device so that various patterns of loading may be set up for unattended running. In this way it should be possible study the effect of relatively moderate stress levels and -combinations but repeated many times during an extended time period.

Before loading the soil sample it should be possible to establish a certain water tension in the sample. This tension should be maintained during the mechanical loading.

Measurements

During the loading process the apparatus should allow measurement of both the loading intensity and the soil's response to this. For the loading intensity the magnitude of the stress levels may be measured indirectly by individually recording the forces on the faces setting up the normal stress and the face for the shear stress. Additionally, the shear magnitude, i.e., the length of the movement of the shearing face, should be measured.

The reaction of the soil should primarily be measured in terms of sinkage of the stress faces. Here it should be observed that the shear face may have a sinkage different from the normal stress faces.

DESIGN

The most feasible design of the loading apparatus turned out to be a modified type of shear ring device. The modification, as compared to a more traditional type like the device described in (2), concerns the way the surface stresses are set up by the loading head. For the traditional device the soil surface outside and inside the ring is unloaded concerning normal as well as shear stresses. This means that as the soil below the ring is loaded it will have the possibility to move laterally out of the way below the ring in order to escape the stress field. Therefore, the sinkage of the ring - especially during the shearing process - will be false. It does not correctly reflect the soils deformation as a function of the applied stress field as described by (1).

The loading head

For this reason the loading head was designed as shown in Fig. 1. The circular plate which transmits the normal stress and fits into the plastic tube containing the soil sample is divided in three parts. The outer ring-shaped and the central circular part are fixed together by means of a bridge construction and constitutes the static part of the normal load system. The intermediate ring-shaped part constitutes the shear ring itself.

The normal stress from the static part is set up loading the bridge by a vertical force applied to the upper edge of a pair of knife edge bearings located at each end of the bridge. The normal stress exerted by the shear ring is applied by means of another bridge carrying a short vertical axle with a horizontal roller bearing at its top and a knife edge bearing on the top of the roller bearing. Another vertical force is applied to the top knife edge while still - by virtue of the roller bearing - allowing the shear ring to turn.

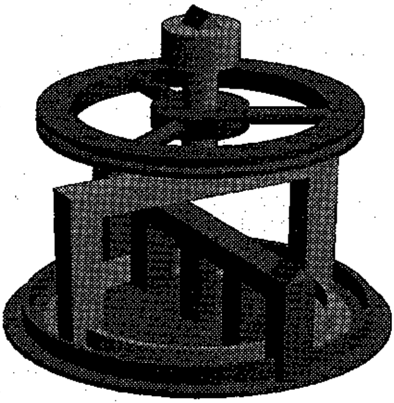

Fig. 1.
Loading head for the apparatus. The normal stress is applied to the soil sample's surface by the lower circular plate. Part of the plate constitutes the shear ring and is shown in a lighter shade of grey.

The shear stress is set up by applying a torque to the vertical axle by means of a drive pulley. Two wires are fixed to the pulley and wound up so that when opposing forces are applied to the wires a torque is set up to the shear ring without introducing side-forces to the loading head. From Fig. 1 it is noted that -due to the bridges - the shear ring may be rotated through only a little less than half a circle. However, the resulting shear length was considered sufficient.

In order to transmit the shear stress to the soil the bottom faces of the loading plates are covered with a sandpaper of grain size P16, i.e., a relatively coarse quality.

Normal stress system

The normal stress for both the static and shear ring part of the loading head is set up by means of dead weights. The arrangement is shown in Fig. 2. The required normal forces on the loading head are accomplished by the use of 2 levers resting in points with a knife edge bearings. Referring to Fig. 2 both levers are restricted in their movements at their right ends. They are resting on the loading head via the bearings at the intermediate points so that the upper lever loads the shear ring part and the lower one loads the static part of the head. Both levers are loaded by the common dead weight at the left ends. The loading ratio for the individual levers are adjusted according to the area of the shear ring and the static part respectively. In this way the static part and the shear ring may - within certain limits - have different sinkages and still the same normal stress will be maintained on both surfaces.

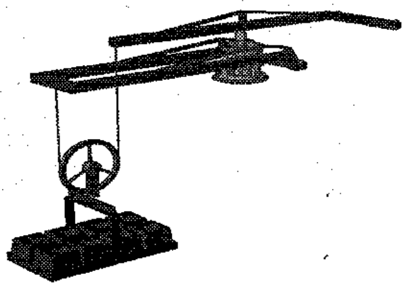

Fig. 2.
Loading arrangement for the normal stress. The upper lever controls the normal stress for the shear plate and the lower one for the static part of the loading head. At their right end both levers are suspended in a knife edge bearings and thus restricted with respect to translational movements. The loading head is shown below the intermediate bearing points on the levers.

The diameter of the loading face is 0.293 m and thus the area amounts to 0.0674 m^2. The system is dimensioned for a maximum normal stress of 200 kPa.

Shear stress system

The shear stress on the sample surface is accomplished by means of a wire system and an electric motor as shown in Fig. 3. At the loading head the torque is set up by opposing forces in 2 wires in order to avoid a side force on the head. The motor assembly pulls the wire by means of a ball-nut moved linearly along a screw-axle which is rotated by the motor via a worm-gear.

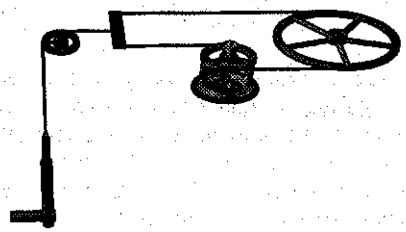

Fig. 3.
The shear stress system. The loading head is shown in the middle of the figure. The torque required to set up the shear stress below the shear ring is brought about by means of a wire system and a linear electric motor shown to the left.

The outer diameter of the shear ring is 0.232 m and the inner is 0.174 m which means that the area of the ring is 0.00264 m^2. The rotational movement of the shear ring is restricted by the mechanical construction to app. half a circle, thus maximum shear length measured at the mean radius is 0.29 m. The device is designed for a maximum shear stress of 150 kPa.

Measuring system

During a loading cycle the soil sample's reaction is measured by means of various techniques. The force that accomplishes the normal stress is currently not measured. Because this force is set up using dead weights it is assumed that it may be calculated with sufficient accuracy.

The bridge which transmits the torque to the shear ring is instrumented with strain gages. In this way the torque is measured as close as possible to the shear ring and the shear stress is then calculated based on the area of the ring.

The movements of the static and shear parts of the loading head are measured using a video camera which records various markings on the head. The images are transmitted to a computer which calculates the movements of the markings. The arrangement is shown in Fig. 4.

The bridge combining the outer and inner static parts are equipped with a slab that holds a small circular white marking. This marker will move vertically thus reflecting the sinkage of the normal stress parts of the head. A semi-circular plate equipped with a triangular white marker is mounted to the bridge for the shear ring. As the ring sinks the marker - specifically the horizontal lower edge - will move downwards correspondingly.

A video camera, shown to the lower right, is directed towards the small circular marker. The essential details in the camera's image is shown schematically within the frame in the right part of the figure. Here the markers that appear white in the image is shown grey-shaded. The image frame is stationary with respect to device's mainframe. Thus, the circular marker's vertical position in the image monitors the sinkage of the normal stress part of the loading

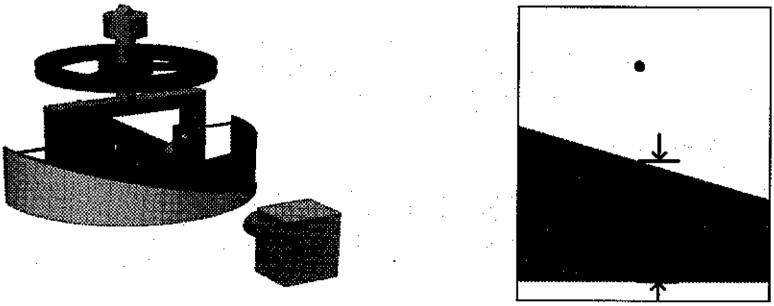

Fig. 4. Arrangement for measuring the movements of the loading head. Left part of the figure shows the head mounted with markers and the video camera. The right part shows schematically the essential details in the image.

head. Similarly, the vertical position of the lower edge of the triangular marker shows the sinkage of the shear ring. Finally, the height of the triangular marker right below the circular marker shows the actual angle of rotation for the shear ring. This height is indicated in the figure as the vertical distance between the arrows.

The video image is transferred to an image analysis system in a computer and the positions and distance mentioned above is determined by means of a suitable program.

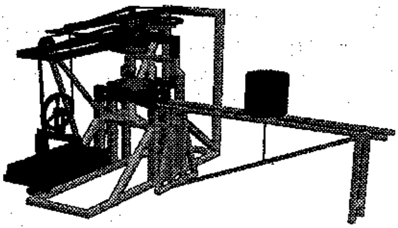

Fig. 5.
Overall appearance of the loading device. A soil sample ready for testing is shown on an auxiliary frame.

In Fig. 5 the entire loading device is shown in total. A soil sample ready for testing is shown on the framework beside the loading device itself. As earlier mentioned, the normal stress is set up by means of dead weights. It is, however, possible to use electrical or hydraulic power devices instead if computer-controlled loading should be desired in the future.

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SOIL RESPONSE TO CONFINED UNIAXIAL COMPACTION AT DIFFERENT MOISTURE CONTENTS

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ABSTRACT

Soil samples from a field trial in which conventional tillage is being compared to other tillage systems in a long-term experiment were compressed uniaxially at different stresses (101, 203, 407 and 815 kPa) and gravimetric moisture contents (7.5, 12.5, 16.8 and 20.7%). The variables considered in assessing soil response were specific volume and tensile strength. Soil specific volume decreased linearly with the log of the applied stress, while the log of tensile strength increased linearly with the log of the applied stress. For each stress of compaction, maximum soil strength was reached at 16.8% moisture content. Tensile strength increased with increasing water content up to 16.8%.

INTRODUCTION

The use of increasingly large, heavy equipment is a day-to-day reality in all agricultural areas in which mechanized methods are used. This may be harmful, since the weight acting upon the elements supporting the machines and the passing of these machines over the ground are both factors which greatly affect the topsoil and subsoil compaction. This compaction is one of the limiting factors to crop development, since it increases the mechanical resistance to root growth. In addition, it reduces the volume of the pores in the soil and modifies the way in which they are distributed, as a result of which the movement of water and the diffusion of gases towards the roots are made more difficult or even prevented (1).

The effects arising from the process of soil compaction depend on the value of the stresses applied and the aptitude for compaction exhibited by the soil. These effects are characterized by a series of variables referring to certain of the physical properties of the soil, such as for example specific volume, the permeability of air and water, the capacity to retain water and tensile strength.

Laboratory tests simulating the effects on the soil of the passage of agricultural machinery have recently been performed (2),(3). The uniaxial compaction test was used to assess the compaction susceptibility of the soil, in spite of the fact that uniaxial stress cannot be either controlled or measured. For Koolen (4) this is not particularly important, since the uniaxial stress to which the soil is subjected in the ground has little influence on the compaction process. This depends fundamentally on the normal stresses applied to the ground by the supporting elements of the agricultural equipment.

The main objective in the work was to use the uniaxial compaction test to assess the response of tilled soil when compacted at different moisture contents. The variables considered in assessing this response were specific volume and tensile strength.

MATERIALS AND METHODS

During the course of a tillage experiment being carried out at the "El Encín" experimental station, belonging to the Autonomous Community of Madrid, soil samples were taken at a depth of 0-10 cm, from plots tilled using the conventional system. The total number of samples collected was eight, two from each of the four plots tilled using this system.

In the laboratory, the soil was air dried until a constant value of moisture was achieved, and was sieved using a 2 mm mesh. Samples of 50 g were taken from the fraction that passed through this mesh, and were mixed with water until gravimetric moisture contents of 5, 10, 15 and 20% were achieved. To this purpose, the samples were inserted in plastic containers which were hermetically closed and placed in a refrigerator for seven days, until uniform moisture conditions were reached. In view of the fact that soil dried in the air conserves a minor quantity of water, the average moisture of the samples was slightly higher than that originally established, with values of 7.5, 12.5, 16.8 and 20.7% being attained, respectively.

The soil was a clay loam (42.8% sand, 29.6% silt, 27.5% clay) with very low organic matter content (1.03%). Its plastic and liquid limits were 15.0% and 24.0%, respectively , whereas field capacity was 16.1%. The actual density of the mineral particles was 2.70 Mg/m^3.

For the compaction test cylindrical, stainless steel rings were used, measuring 50 mm in internal diameter and 25 mm in height. These were filled with soil, with care being taken to prevent compaction. The average dry weight of the soil in the cylinders was 35.41 ± 0.23 g.

Uniaxial compaction of the cylindrical soil probes was accomplished using a universal testing machine (Instron 1122). The compaction forces were 200, 400, 800 and 1600 N, equivalent to actual compaction stresses of 101, 203, 407 and 815 kPa. Eight replications were performed for each value of compaction stress and moisture content. The displacement of the machine's header was established at a descent rate of 0.83 $mm.s^{-1}$ (50 $mm\text{-}min^{-1}$). At this speed, the deformation gradient was 0.04 s^{-1}.

On completion of the compaction process the samples were dried in an oven for 24 hours at a temperature of 105-110°C. The dry probes were subsequently removed from their rings and taken once more to the universal testing machine for breaking them down following the "Brazilian Test" methodology, as described by Dexter (5). Before failure, their diameter, d, and thickness, l, were measured with a gauge. Once the compressing force, F, causing soil failure was Known, soil tensile strength was estimated by the following expression: $\sigma = 2 \cdot F / \pi \cdot d \cdot l$.

RESULTS AND DISCUSSION

Figure 1 shows the variation in the specific volume of the soil versus the compaction stress applied for each of the moisture contents considered. Specific volume decreases linearly with the log of compaction stress. For a given compaction stress, the values of specific volume reached were smaller as the moisture content of the soil increased, as long as this latter variable did not reach a value of 20.7%, since in this case the specific volume of the soil was identical to that corresponding to 16.8% moisture.

When the variation in specific volume versus soil moisture content were represented for each compaction stress, the values obtained followed the trend shown in Figure 2. Specific volume decreased with soil moisture content until the latter variable reached a value of 16.8% Above this value of moisture, 20.7%, the specific volume stabilized at values analogous to those corresponding to a moisture of 16.8%. Likewise, for a given value of moisture content, specific volume was smaller as compaction stress increased.

For each of the compaction stresses considered the strength of the soil dried in the oven varied in a non-linear fashion with compaction moisture (Fig. 3). This resistance in fact increased with moisture to a maximum value when the latter variable was at 16.8%. Above this value of moisture, soil strength decreased, this decrease being more accentuated at a compaction stress of 815 kPa than at the other three values. Likewise, and for each moisture content, the values of soil strength were higher as the compaction stress increased. The effects of the latter became more accentuated as moisture content increased, the largest differences being observed with the highest values of soil strength (Fig. 3).

The impact of the compaction stress applied on soil strength after oven-drying may be appreciated in Figures 4a and 4b. Soil tensile strength increased with compaction stress and, for a given value of the latter, increased as the soil moisture content at compaction rose from 7.5% to 16.8%. With moisture contents of 20.7%, the values of soil strength were practically equal to those corresponding to a moisture content of 16.8%.

Attempts were made to develop an empirical expression relating tensile strength, σ_t, to gravimetric soil moisture content, H, and compaction stress, σ_c. The equation adjusted was as follows

$$\sigma_t = a+bH^2+cH^3+\sigma_c$$

were σ_t and σ_c are expressed in kPa, and H in percentage.

The values obtained for the constants, a, b, c and d, were respectively, 233.9, 3.34, -0.12 and 0.30. The coefficient of determination, r^2, was 0.88 ($P<0.001$).

The most relevant fact underlined by the results obtained is the importance of soil moisture content in the process of soil compaction. Indeed, the isobars relating specific volume to moisture content on compaction outline two different processes (Fig. 2), one in which specific volume, and consequently porosity, decreases with moisture, and another in which this tends to increase with moisture. These two compaction processes were defined by Koolen (4) as dry compaction and moist compaction. In response to an

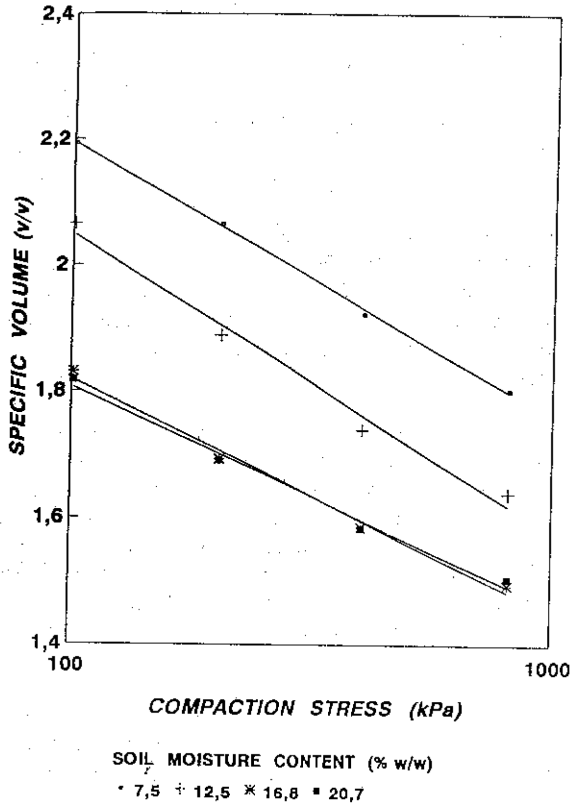

Fig. 1. Variation of the specific volume with compaction stress at different moisture contents.

external force, the mineral particles of the soil are reorientated until a reaction balancing this force is generated between them. This process occurs at the cost of a reduction in the volume of the pores in the soil. The water contained in the soil acts as a lubricant, facilitating the movement of the mineral particles and producing this resistance. When moisture content is high, the water may limit the compaction process, since the reduction of the volume of the pores takes place after the water has left them. In the soil tested, the moisture content separating one type of compaction from the other was 16.8 %.

Soil strength, in spite of having been determined after the soil probes were oven-dried, constitutes a measure of the ease with which the clods produced when tilling a compacted soil may be broken. The results shown in Figure 3 are in keeping with those obtained for specific volume (Fig. 2), since for each of the compaction stresses considered the maximum soil strength occurred when specific volume reached its lowest value.

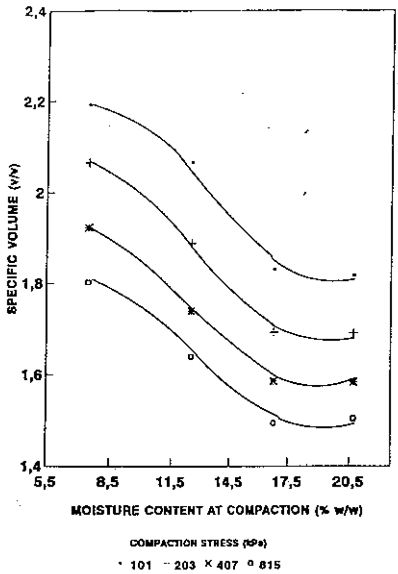

Fig. 2. Variation of specific volume with soil moisture at different compaction stresses.

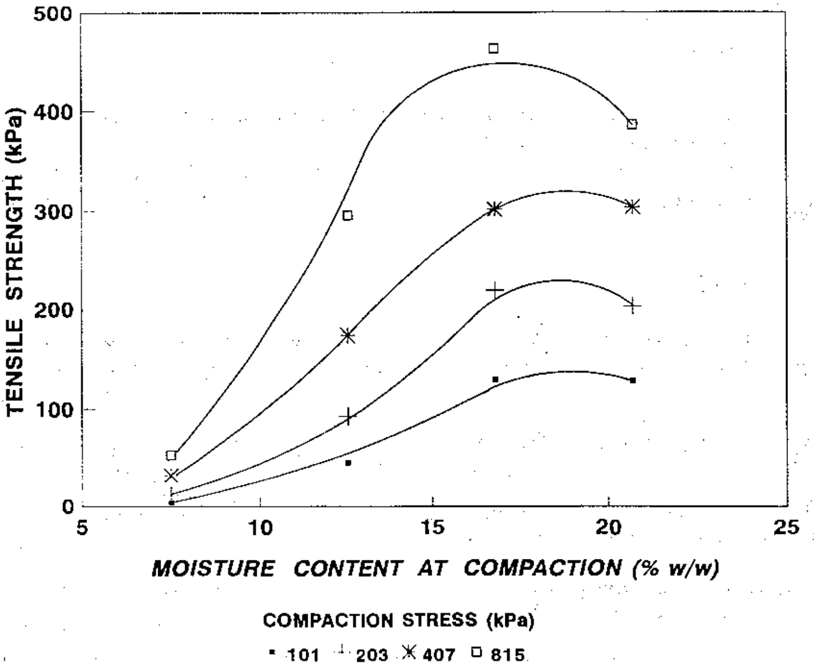

Fig. 3. Soil strength as a function of soil moisture content at different compaction stresses.

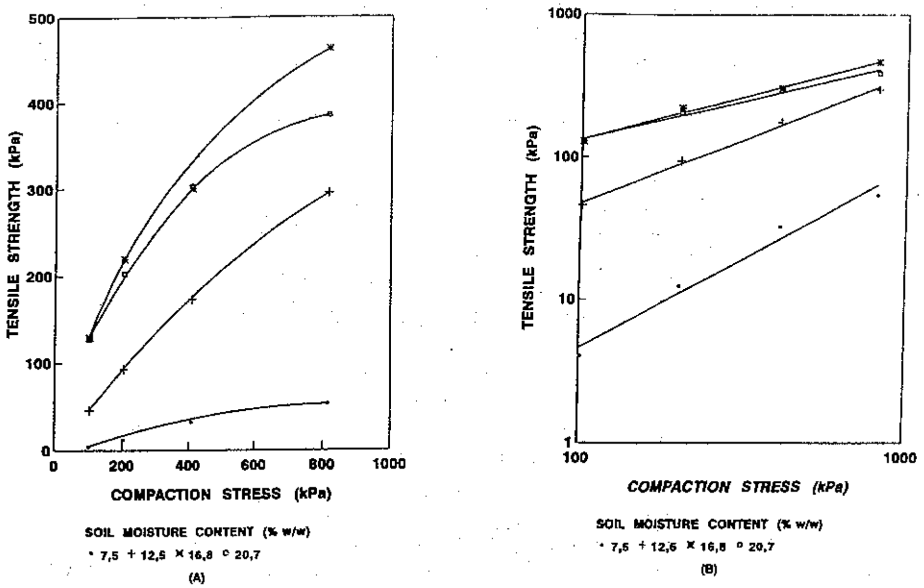

Fig. 4. Soil strength as a function of compaction stress. A) natural scale and B) log-log scale.

CONCLUSIONS

The uniaxial coompaction test,revealed that moisture content and normal stress are the two variables governing soil compaction. The soil moisture content underlying the two different processes of compaction was 16.8%, which is too close to field capacity. At this moisture, and for each compaction stress, the soil reached the highest tensile stress.

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TILLAGE EFFECT ON PHYSICAL PROPERTIES OF NEAR-SURFACE SOIL

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ABSTRACT

The objective of this study was to assess the impact of tillage and crop sequence on near-surface properties in the laboratory using large undisturbed soil cores. Samples were collected from a long-term tillage study in southeastern Nebraska (96°24' W and 40°59' N) in the fall just prior to harvest. A split-split-plot design was employed to evaluate differences in soil properties among continuous corn (*Zea mays* L.) and corn after soybean (*Glycine max* (L.) Merr.); moldboard plow, ridge till and no-till; and 0- to 50-, 50- to 100-, and 100- to 150- mm depths. Soil properties assessed included bulk density, penetrometer soil strength, shear strength, WFPS, and organic carbon. Large undisturbed cores of surface soil worked well for soil physical measurements where water potential needed to be kept constant. Penetrometer soil strength, shear strength, and organic carbon were generally greatest in no-till and least in moldboard plow. Across tillage treatments, strength measurements increased with depth. Differences in organic carbon among tillage treatments were largely confined to the 0- to 50- mm depth.

INTRODUCTION

The physical integrity of the soil surface is critical to the sustainability of the soil as a natural resource. Conditions of the soil surface directly impact infiltration and soil erodibility, which in turn influence environmental quality. The surface layer of soil is the most dynamic zone in the profile. It represents a zone of high energy exchange, and is characterized by rapid changes in temperature and water content. It is also most impacted by soil management decisions of tillage, crop sequence, and fertilization.

Near-surface soil properties are important in understanding soil management and processes influencing water and wind erosion. Shear strength is used in the water erosion prediction project (WEPP) currently being developed in the United States. The fall-cone penetrometer is a good indicator of soil crust strength because measurements generally represent the 1- to 2- mm depth (1). The fall-cone has been used to measure in situ soil strength (2). Control of water potential in the immediate soil surface under field conditions, however, is very difficult. For repeated measurements of undisturbed soil conditions under controlled water potential, there is a need to utilize laboratory as opposed to field procedures.

We sought a laboratory method to measure soil properties in relatively thin zones within the surface layer. To do this, we used large cylinders to collect undisturbed cores and measured selected soil properties in the laboratory under controlled water potential. The sensitivity of the method was tested over tillage and crop treatments.

The objective of this study was to assess the impact of tillage and crop sequence on near-surface properties in the laboratory using large undisturbed soil cores.

MATERIALS AND METHODS

Plot History

A long-term study was started in 1978 at the University of Nebraska-Lincoln, Rogers Memorial Farm, near Lincoln, NE (96°24' W and 40°59' N). Soil at the site was a Sharpsburg silty clay loam (fine, montmorillonitic, mesic Typic Argiudoll). Tillage treatments included in the study were moldboard plow, chisel, subsoil, disk, ridge till, and no-till. Primary tillage for moldboard plow, chisel, and subsoil was performed in the fall. Spring disking was conducted on all tillage systems except ridge till and no-till. Soil disturbance in ridge till was limited to row scraping at planting and cultivation and ridge reformation after crop emergence. Continuous corn was planted on the site from 1978 to 1984. In 1985, each tillage plot was divided into four subplots (23 m long x 4.6 m wide) to which crop sequences of continuous corn, corn after soybean, soybean after corn, and continuous soybean were assigned. Nitrogen fertilizer, at a rate of 100 kg N/ha-y was the only plant nutrient applied when cropped to corn. Weed control was achieved by herbicides in no-till and by herbicide, tillage, and cultivation in the other tillage systems.

Field Procedures

Treatments included in this study were moldboard plow (MP), ridge till (RT), and no-till (NT) tillage systems and continuous corn (C-C) and corn after soybean (C-S) crop sequences. Treatment combinations were replicated four times. Undisturbed soil cores were collected from the nontrafficked interrow of each treatment in the fall of 1992, just prior to harvest. Samples were collected in stainless steel cylinders (300 mm diameter x 200 mm height). The cylinders were hand pressed into the soil by alternatively pressing downward and cutting soil away from the leading edge of the cylinder. Cylinders were inserted 30- to 40- mm below the tillage depth into the mechanically compacted zone which was necessary to retain soil in the cylinder. Soil at the bottom of each cylinder was separated with a wire. Upon collection, each sample was placed in a 23 L tub, wrapped in plastic, and transferred to the laboratory.

Laboratory Procedures

The surface of each sample was divided into three equal areas by pushing steel plates into the soil in a pattern radiating out from the center. Two areas were excavated to depths of 50 and 100 mm below the original surface The remaining third represented the surface condition and was not excavated. Working from the 100 mm depth upwards, soil properties were assessed at a water potential of -0.5 kPa as determined by depth of water below the soil surface. Soil strength was measured with a Geonor g-200 fall-cone penetrometer with a 60 g, 60° cone (Geonor A/S, Oslo, Norway)[1]. Soil shear strength was measured with an Edeco Pilcon torvane with a vane of 33 mm diameter and 50 mm length (English Drilling Equipt. Co. Ltd., Huddersfield, England). Bulk density was determined using the compliant cavity method (3). The apparatus for the cavity had a 70 mm inner

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[1] Mention of commercial products is solely to provide information and does not constitute endorsement by USDA-ARS or the University of Nebraska over other products not mentioned.

diameter and the depth of soil excavation was 10- to 20- mm. Ten fall-cone penetrometer, three torvane, and one bulk density measurement was made on each soil depth. Water content was assessed from samples taken for bulk density. Water-filled pore space was calculated as $(\emptyset_W \times P_B)/TP$, where $\emptyset_W$ was gravimetric water content, P_B was bulk density, and TP was total porosity (4). Organic carbon was determined in a different study by procedures previously outlined (5).

Tillage, crop, and depth effects for all soil properties were evaluated by analysis of variance with tillage as the whole plot factor, crop as the split-plot factor, and depth as the split-split-plot factor. Comparisons for main and interactive effects were made using least significant differences at $P \leq 0.1$ (6).

RESULTS AND DISCUSSION

The large diameter core method worked well for providing relatively undisturbed surface soil samples necessary for conducting soil physical measurements under controlled water potential.

Analysis of variance indicated that crop did not influence any of the measured soil properties (Table 1). Tillage significantly influenced soil and shear strength, WFPS, and organic carbon. Depth significantly influenced all measured soil properties at $P \leq 0.05$. Depth x Tillage influenced bulk density, shear strength, WFPS, and organic carbon. Only soil strength was significantly influenced by the Depth x Tillage x Crop interaction.

Table 1. Summary of F-test significance levels for analysis of variance, showing main and interactive effects of tillage, crop, and depth on soil physical and chemical properties.

Source of Variation	Bulk Density	Soil Strength	Shear Strength	WFPS	Organic Carbon
Tillage	NS	**	**	*	**
Crop	NS	NS	NS	NS	NS
Tillage x Crop	NS	NS	NS	NS	NS
Depth	**	**	**	**	**
Depth x Tillage	**	NS	**	**	**
Depth x Crop	NS	NS	NS	NS	NS
Depth x Tillage x Crop	NS	**	NS	NS	NS

**, * Significant at $P \leq 0.05$ and 0.1, respectively.
NS Not significant at $P \leq 0.1$.

Bulk density increased with depth in each tillage treatment (Table 2). Averaged over depths, bulk density was not different among tillage treatments. Values for bulk density were 15- to 20-% lower than previously reported for this soil (7). A predominance of montmorillonitic clay caused soil swelling with the addition of water resulting in lower bulk density.

Table 2. Mean comparisons of bulk density, penetrometer soil strength, shear soil strength, water-filled pore space, and organic carbon averaged over crops. Least significant differences (LSD) at $P \leq 0.1$ are given for the interactions.

	Tillage				
Depth (mm)	No Till	Ridge Till	Moldboard Plow	Mean	LSD for Tillage within Depths
	Bulk Density (Mg m^{-3})				
0-50	0.69	0.97	0.92	0.86 c	0.11
50-100	1.10	1.00	0.96	1.02 b	0.13
100-150	1.23	1.10	1.11	1.15 a	0.12
Mean	1.01	1.02	1.00		
LSD for Depths within Tillage	0.09	0.10	0.13		
	Penetrometer Soil Strength (kPa)				
0-50	9.5	9.9	7.1	8.9 c	3.1
50-100	29.3	21.0	9.9	20.1 b	13.8
100-150	34.3	29.5	20.6	28.1 a	14.8
Mean	24.3 x	20.1 y	12.5 z		
LSD for Depths within Tillage	9.9	14.2	11.0		
	Shear Soil Strength (kPa)				
0-50	5.4	4.1	2.3	3.9 c	1.2
50-100	12.2	7.7	5.5	8.5 a	3.0
100-150	9.2	7.5	6.3	7.7 b	2.2
Mean	8.9 x	6.4 y	4.7 z		
LSD for Depths within Tillage	2.4	2.0	1.4		
	Water-filled Pore Space (%)				
0-50	42	67	53	54 c	9
50-100	71	69	65	68 b	11
100-150	79	75	74	76 a	9
Mean	64 y	70 x	64 y		
LSD for Depths within Tillage	6	11	12		
	Organic Carbon (kg C m^{-3} soil)				
0-50	27.8	20.1	16.0	21.3 a	3.0
50-100	21.2	20.1	18.2	19.9 b	1.7
100-150	21.4	19.5	18.3	19.7 b	1.6
Mean	23.5 x	19.9 y	17.5 z		
LSD for Depths within Tillage	1.9	1.4	1.1		

Values for main effects followed by the same letter within a column (a,b,c) or row (x,y,z) are not significantly different at $p \leq 0.1$.

Trends in penetrometer and shear strength were similar among tillage treatments and depths (Table 2). Strength was generally greatest in no-till and least in moldboard plow. Strength increased with depth in all tillage treatments. At 0- to 50- mm, crust strength was low because the soil surface at the time of sampling was well protected from rain by the plant canopy. As compared to the lower two depths, shear strength at 0- to 50- mm was lower due to surface incorporation of residue and a loose, granular soil structure.

Water-filled pore space increased with depth in all tillage treatments (Table 2). Averaged over depths, ridge till possessed significantly greater WFPS as compared to no-till and moldboard plow. Maximum aerobic microbial activity has been found to occur near 60% WFPS (4).

Averaged over depths, organic carbon was greatest in no-till and least in moldboard plow (Table 2). Differences in organic carbon among tillage treatments were largely confined to the 0- to 50- mm depth. At 0- to 50- mm, organic carbon in no-till was 74% greater than moldboard plow and 38% greater than ridge till.

CONCLUSIONS

Large undisturbed cores of surface soil worked well for soil physical measurements where water potential needed to be kept constant. Penetrometer soil strength, shear strength, and organic carbon were generally greatest in no-till and least in moldboard plow. Across tillage treatments, strength measurements increased with depth. Differences in organic carbon among tillage treatments were largely confined to the 0- to 50- mm depth. Understanding the soil physical characteristics of the near-surface layer is important in making sound soil management decisions that affect erosion prediction and control.

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GROUSER HEIGHT DEPENDENCE IN THE BEVAMETER PERFORMANCE

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ABSTRACT

The maximum torque measured in a shear annulus experiment on sand is found to have an unexpected dependence on the grouser height. A standard analysis of the experimental data yields an unphysical height variation in the cohesion and in the friction angle. Based on a free-body diagram we propose a qualitative explanation for the height dependence due to an uneven normal stress distribution over the failure surface caused by the application of torque to the bevameter. A consequence of this is that the standard analysis of bevameter data should be reconsidered.

INTRODUCTION

In textbooks (1) and in the literature (2,3) where the performance of the bevameter and the shear annulus are described, there is no discussion of a possible grouser height effect in the performance of the instruments. In a lecture series we wished to demonstrate with a shear vane that soil shear strength did not vary with the depth. However, the students never got their demonstration as we found an unexpected vane height dependence. This finding has been followed up by several experiments where we have tried to get rid of the effect, but so far the effect remains. Below we will describe an experiment where the effect is demonstrated and we will give a qualitative explanation.

EXPERIMENT

The instrument

The instrument is shown in figure 1a and 1b. Grousers with different heights could be placed in the twelve slits giving a grouser spacing of 30°. We used heights from 2 to 14cm. The annulus had an inner diameter $2r_i$=14.0cm and an outer diameter $2r_o$=24.0cm. Extra dead weights up to 350N could be put on the top of the instrument. The instrument frame was hindered from rotating by three solid spikes hammered into the soil. The shear rotation angle was measured by a potentiometer and the torque was computed from the force measured by a load cell. A datalogger with a sampling frequency of around 10 Hz was used to collect the data later to be analysed on a PC.

The soil

The instrument is constructed as an easy-to-carry field instrument. However, the experiment reported in this paper is a laboratory experiment performed on a well defined sand; dry bulk density $1.53 \cdot 10^3$ kg/m³, grain size less than 2mm and median grain size by weight, 0.36mm. About 150kg sand was kept in a harrel with a drainage hole in the bottom. Water was added at the top until it dripped from the drainage hole. The experiment was run shortly after the dripping had stopped. The sand was then saturated having a moisture content by volume of around 20% or by weight around 13%. The sand inside and outside the annulus was excavated to a depth equal to the grouser height ensuring that the only failure plane was the one under the instrument.

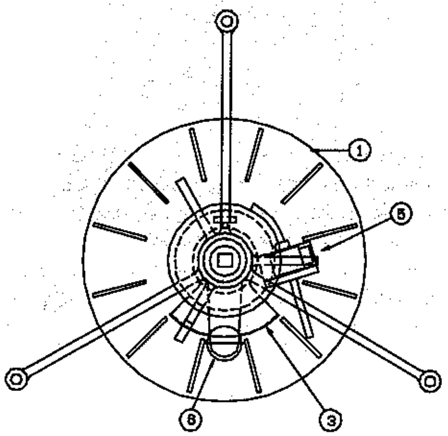

Figure 1a

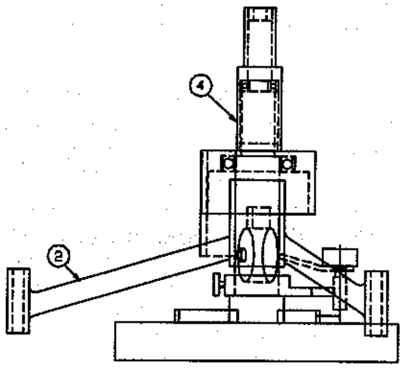

Figure 1b

Figure 1. The shear annulus instrument seen from above in figure 1a and seen from left in figure 1b. The numbers in the figures refer to: 1.The top plate with the 12 slits for the grousers. 2.Arms with holes for spikes to hinder the instrument from rotating. 3.Gear wheel segment to transmit the rotation to 6. the rotary potentiometer. 4. Grip for the torque key. 5. The load cell that measures the turning force.

Data handling and results

An example of the experimental data is given in figure 2. The torque is plotted versus the rotation angle. Most of the experimental runs had the shown, expected shear stress - displacement behaviour for sand, as reviewed by Okello (2). From the experimental curve the maximum torque and the rotation angle giving the maximum torque, is determined. In figure 3 the maximum torque is plotted as a function of grouser height for different loads.
The behaviour shown in figure 3 is typical for all the kinds of soil and sand we have investigated. The maximum torque and accordingly the shear strength we find has a significant dependence on the grouser height and on the dead weight loading the instrument. The strong grouser height dependence we get has to our knowledge, not previously been taken into account when analysing shear annulus data to determine shear strength, cohesion and friction angle. The only height dependence considered so far has been the increase in the normal stress with the depth due to the weight of the soil. It is shown below from the free-body diagram of the soil, that another non-trivial grouser height dependence is inherent in the problem.

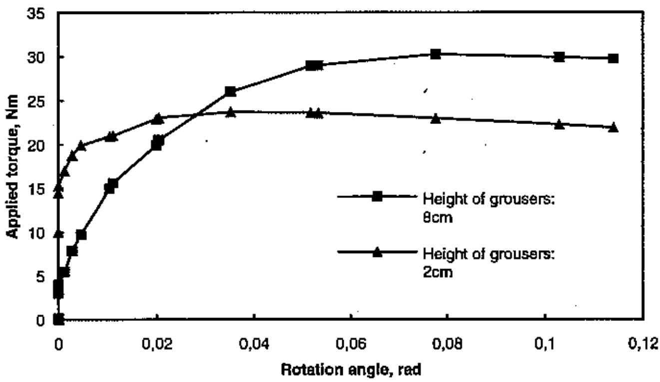

Figure 2. The applied torque as a function of rotation angle for two different grouser heights 0.02m and 0.08m. The extra dead weight was 245N.

Figure 3 indicates an uneven increase in the torque as a function of load for a given grouser height. The reason is likely to be found in how the instrument was loaded. We did not take any precautions to ensure a symmetric loading.

If the center of mass for the load is slightly off the vertical axis of the instrument this will result in an uneven normal stress distribution over tbe failure surface. Our understanding of the observed height effect indicate that this asymmetry may lead to an increase in the maximum applied torque.

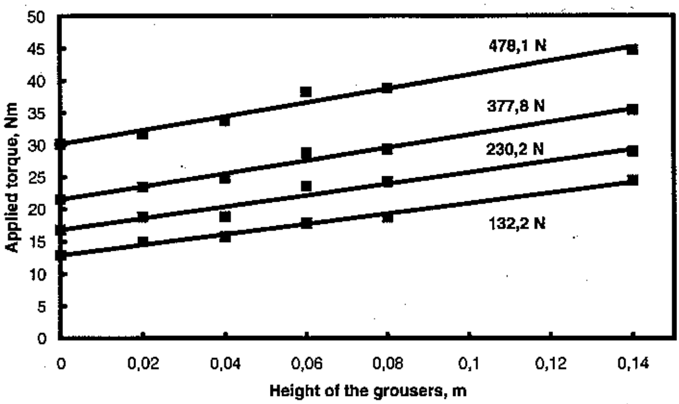

Figure 3. The maximum applied torque as a function of grouser height for four different loads. Each value is the average of 4 to 15 different runs. Also shown are the extrapolated values for h=0 obtained from a linear regression of the data shown in the figure.

Standard analysis (2) assumes an even distribution of the normal stress and the shear stress over the failure surface. The maximum shear stress τ_{max} is then given by

$$\tau_{max} = \frac{3T_{max}}{2\pi\,(r_o^3 - r_i^3)} \tag{1}$$

where T_{max} is the maximum torque, r_o is the outer radius of the annulus and r_i is the inner radius. The normal stress is given by

$$\sigma_N = \frac{N}{\pi\,(r_o^2 - r_i^2)} \tag{2}$$

where N is the total normal load on the failure surface. The Mohr-Coulomb relation gives the relationship between the shear stress, the normal stress, the cohesion c and the soil friction angle φ.

$$\tau_{max} = c + \sigma_N \tan\varphi \tag{3}$$

Analysis of the data in figure 3 using eqs. (1), (2) and (3) yields the results presented in Table 1. The results for $h > 0.02$m show an increase in the cohesion and in the friction angle with the grouser height. These apparent variations with the grouser height seem unphysical and are unlikely to reflect real variations in the cohesion and in the friction angle. Data analysis described below incorporating a grouser height dependence, yields the values in the last row in table 1, $c = 3.3$ kPa and $\varphi = 19.8°$. These limiting values are in our opinion, the most correct values for cohesion and friction angle in the surface layer of the investigated sand.

Table 1. The cohesion c and the soil friction angle φ for a sand at moisture content of 20% by volume, determined at different grouser heights. The values at h=0.00 m are determined by an extrapolation procedure described in the text.

Grouser height h (m)	Cohesion c (kPa)	Friction angle φ (deg)
0.02	3.9	19.4
0.04	3.8	21.0
0.06	4.3	24.2
0.08	4.5	23.6
0.14	5.7	24.4
0.00	3.3	19.8

The main reason for the height dependence is the assumption of an even stress over the failure surface. This should be modified (4). Over the failure surface one can separate between the normal stress, σ_N, due to the normal applied load, N, and a normal stress, $\sigma_T(h,\tau_{max})$, due to the applied torque. Using Eqs. (1) and (2) and assuming the Mohr-Coulomb relation we can write

$$\tau_{max} = c + \sigma_T(h,\tau_{max})\tan\varphi + \sigma_N \tan\varphi \tag{4}$$

At $h = 0$ we have $\sigma_T(0,\tau_{max}) = 0$. This implies that when plotting τ_{max} vs h at a given load and extrapolating linearly to $h = 0$ we get a set of data (τ_{max},σ_N) with no grouser height influence. Accordingly assuming the Mohr-Coulomb relation one can determine cohesion and friction angle using Eq. (3).

A FREE-BODY DIAGRAM

The performance of the bevameter is illustrated by figure 4. In use the soil inside the inner ring and the soil outside the instrument is excavated. The shear surface is the annular ring. When applying the torque to the instrument the back side of the grousers is stress free. Let us consider the curved slice *abcd* in figure 4 and let it, for analytical simplicity be assumed rectangular and plane. A free-body diagram of the slice is shown in figure 5. The force F

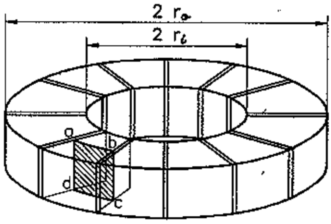

Figure 4. The action of the bevameter. The radial grousers transfer the torque to the soil in the annulus with inner radius r_i and outer radius r_o. The soil in the inner cylinder and outside bevameter is excavated. A free-body diagram of the slice of soil *abcd* is considered in figure 5.

transmits the torque to the slice. The line of action for the force ***F*** is not known. With a uniform stress distribution over the grouser side the action point is at the center, however as long as the action line is above the failure plane the arguments to be presented are valid. The force ***F*** together with ***S***, the counteracting shear force, makes a couple that must be balanced. In the vertical direction the extra load ***L***, and the weight of the soil ***W***, is counteracted by the normal force *N*,on the failure surface. Static equilibrium of the soil slice gives:

$$\boldsymbol{S} = \boldsymbol{F}\,;\, \boldsymbol{N} = \boldsymbol{L} + \boldsymbol{W} \text{ and } f = \frac{h \cdot F}{N}$$

where the height *h* of the grouser force and the eccentricity *f* is shown in figure 5. This eccentricity results from an uneven normal stress distribution over the failure surface. The grouser force height *h*, the eccentricity *f*, and the uneveness depend on the grouser height.

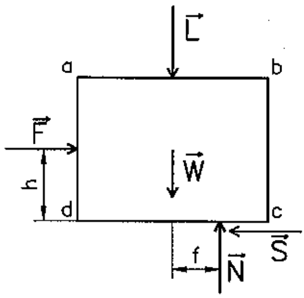

Figure 5. Free-body diagram of soil slice *abcd* in figure 4. The surface *bc* is stress free. ***W*** is the weight of the slice, ***L*** is the external load, ***F*** is the force transferring the torque to the slice and *S* and *N* are resultant forces over the surface *cd* necessary for static equilibrium.

Accordingly, the free body diagram and its consequences indicate that a grouser height dependence should be included in the analysis. Static equilibrium implies an uneven normal stress distribution over the failure surface. This stress distribution over the surface is not known. To make quantitative comparisons theoretical work is needed. One expects failure to start and propagate from the place where the Mohr-Coulomb relation is first fullfilled by the actual stress distribution. The height effect should depend on the number of grousers. Increasing the number would reduce the uneveness of the normal stress and so the effect should be less significant.

This grouser height dependence is not limited to the bevameter. Modifications in the analysis of the results from other shear strength instruments should also be investigated.

CONCLUSIONS

The main experimental finding reported is that when using a shear annulus to determine the shear strength of a soil one gets a maximum torque having an unexpected dependence on the grouser height. A free body diagram shows that static equilibrium implies an uneven normal stress distribution over the failure surface. Failure is expected to be governed by the actual stress distribution. This stress distribution over the surface is not known. Theoretical work is needed.

The height effect is clearly seen in sand where the cohesion is small. In preliminary experiments on more cohesive soils the apparent increase in τ_{max} is enlarged as expected from Eq. (4). The cohesion increases the shear strength and thereby the maximum normal stress due to the applied torque.

In their comparison of different techniques for measuring soil shear strength Stafford and Tanner (3) concluded that the test method affects results and that *in situ* field measurements with the shear annulus is recommended for obtaining the shear parameters. However, when discussing their results they never questioned the assumptions of the formulas used. The standard treatment of our shear annulus data in sand, grouser height 2 cm, yields a cohesion value 20% too high. The theoretical basis for the other techniques should also be examined. This may reduce some of the apparent differences in the shear strength data.

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THE INFLUENCE OF HEAVY SOIL COMPACTION ON THE STRUCTURE OF CULTIVATED LAYER

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ABSTRACT

The study of Haplic Phaeozem compaction by tractor wheel was conducted. The micromorphometric analysis has enabled to describe the location of zones with varying compaction. The most compacted zone has been found in the wheel track at the depth 4-8 cm.

INTRODUCTION

The increase of soil cultivated layer density is undoubtly one of the biggest problems of the common agrotechnics (1,2). In Europe, where the level of agriculture mechanization is high, the area of soils physically degradeted is 36 Mha, 33 Mha of them due to compaction (3).

Among soil factors, which influence soil compactability, porosity and moisture content are meaningfull (4,5).

However, the soil moisture content and soil porosity are important factors determining compaction - the wheel parameters affect compaction, too. The most frequently used wheel parameter is its load and contact pressure. In general, the higher load (and contact pressure when the same tire) - the higher compaction (6). Wheel slip is routinely reported in traction studies, but very rarely in compaction ones (7). The influence of slip on soil compaction is not so univocal, generally in deeper soil layers bigger slip meems higher compaction . But the higher slip resulting from greater pull may cause milling effect in the rut bottom. Such a situation results in density decrease and very significant change of other soil properties. The influence of the other tire parameters like size and deflection should be considered, too.

Macro- and micromorphological analysis enables to recognize and describe the changes occuring in the zone affected by the farm machinery wheels. Because only micromorphometric analysis enables to find the quantitative parameters, so it may be the base for the proper evaluation of changes.

METHODS

The study was conducted on a Haplic Phaeozem developed from loess. Samples for the analyses were taken from the tracks left by front wheel of the 38 kW and 2700 kg tractor.

The granular composition of the cultivated layer of the soil was as follows, in % (w/w): >2mm - 0, 2 mm to 50 µm - 11, 50 µm to 2 µm - 73 and <2 µm - 16. During the compaction the water content of the cultivated horizon was 21.3 g/100 g (about 60% of field water capacity) and its bulk density was 1.32 Mg m^{-3}.

The tractor pass was performed in spring during top-dressing of winter barley. The samples were taken to the metal containers (8 x 9 x 4 cm) on the next day, in the vertical plane from 0-8 cm and 9-17 cm layers from the both track bottom and uncompacted soil. Dried soil was saturated with a solution of Polimal-109 resin. Following the resin polymerization the soil samples were cut into 1 cm thick slices, ground and polished. The samples processed as describe above were used to conduct detailed micromorphological analysis and taking microscope pictures of different zones of observed soil layer. The results of micromorphological analysis were presented in previous paper (8).

The micromorphometrical analysis was a second step in this work. The computer aided stand for picture-analysis was employed. PC-governed picture analyzer IMAGER-512 enabled recording, processing and analyzing of monochromatic pictures. IMAL-256 programm for picture-processing was applied.

The micromorphometrical analysis was completed for 9 zones of the dimensions 1455 x 1455 µm each. Seven zones were selected within compacted (Fig.1) and 2 within uncompacted area.

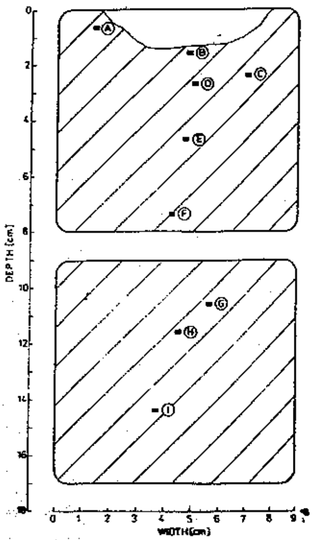


Fig.1. Scheme of the distribution of soil zones in the wheel-track left by a tractor.

The following parameters were selected to characterize soil structure: number of pores, area of pores section in µm x 10 and area of pores section as a % of the surface of analysed zone. The group of pores: >20 µm and <20 µm were analised (Table 1). Magnifying ratio beeing used enabled to record all pores >20 µm; part of the pores <20 µm could be neglected, instead.

TABLE I. Micromorphometric analysis of the soil tested. (area window $Q= 211.66\ 10^4\ \mu m^2$).

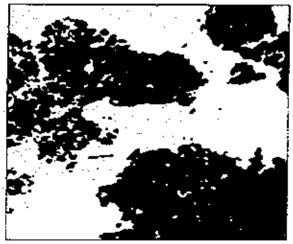
Zones symbol *)	Number of pores			Area of pores, ($10^4\ \mu m^2$)			Content of area pores in area window, (%)		
	>20 µm	< 20 µm	Sum	>20 µm	<20 µm	Sum	>20 µm	<20 µm	Sum
a	66	159	225	107.44	1.17	108.61	50.74	0.55	51.29
b	197	222	419	41.09	2.16	43.25	19.42	1.02	20.44
A	51	151	202	10.60	1.22	11.82	5.01	0.58	5.59
B	45	123	168	14.00	0.97	14.97	6.61	0.46	7.07
C	35	108	143	28.79	0.75	29.51	13.61	0.35	13.96
D	22	61	83	12.31	0.55	12.86	5.81	0.26	6.07
E	85	383	468	4.63	2.33	6.96	2.17	1.10	3.27
F	40	218	222	2.75	1.44	4.19	1.28	0.68	1.96
G	196	852	1048	14.80	5.33	20.13	6.99	2.52	9.51
H	29	77	106	59.18	0.46	59.64	27.97	0.22	28.19
I	74	228	302	10.98	1.65	12.53	5.15	0.78	5.93

*) - explanations of zones as in Figures.

RESULTS

Under tracks formed by front tractor wheel, in the layer 0-18 cm area of pores section was significantly smaller than in uncompacted soil, in which it figured $108.61 \times 10^4\ \mu m^2$ in loose, aggregated zone (Fig.2 a), and $43.25 \times 10^4\ \mu m^2$ inside the aggregate itself (Fig.2 b). In the zone contacted directly by tire the area of pores section was least where soil was only compacted but not fragmented ($11.82 \times 10^4\ \mu m^2$,Fig.3 A). The pores section area was more than double higher where soil was fragmented ($29.54 \times 10^4\ \mu m^2$, Fig.3 C).

a



b

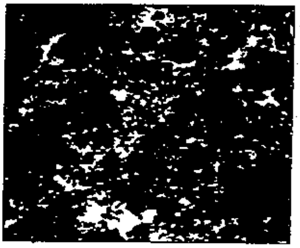


Fig. 2.The structure of uncompacted cultivated layer at a depth of 2-2.5 cm. a - loose zone. b - interior of macroaggregate. Solid phase - black colour. pores - white colour.

The pores section area was getting smaller at the bigger depths (Fig.3 B, D E, F), reaching the minimal value $4.14 \times 10^4\ \mu m^2$ at the depth 7.5 cm. In the 9-17 cm layer the pores section area increased significantly (Fig.3 G,H,I). The value of pore section area is determined by the pores>20 μm. The decrease of their area means the increase of soil density. The least differences between the section areas of the pores >20 μm and pores <20 μm occured in the most compacted zones E and F. The area of section of pores <20 μm does not depend much on soil compaction, the results obtained varied from 0.46 x 10^4 μm^2 to 5.33 x 10^4 μm^2.

The expression of results presented like ratio of area of pores section to total observed area enables to estimate the effect of compaction and precises the location the zones compacted mostly.

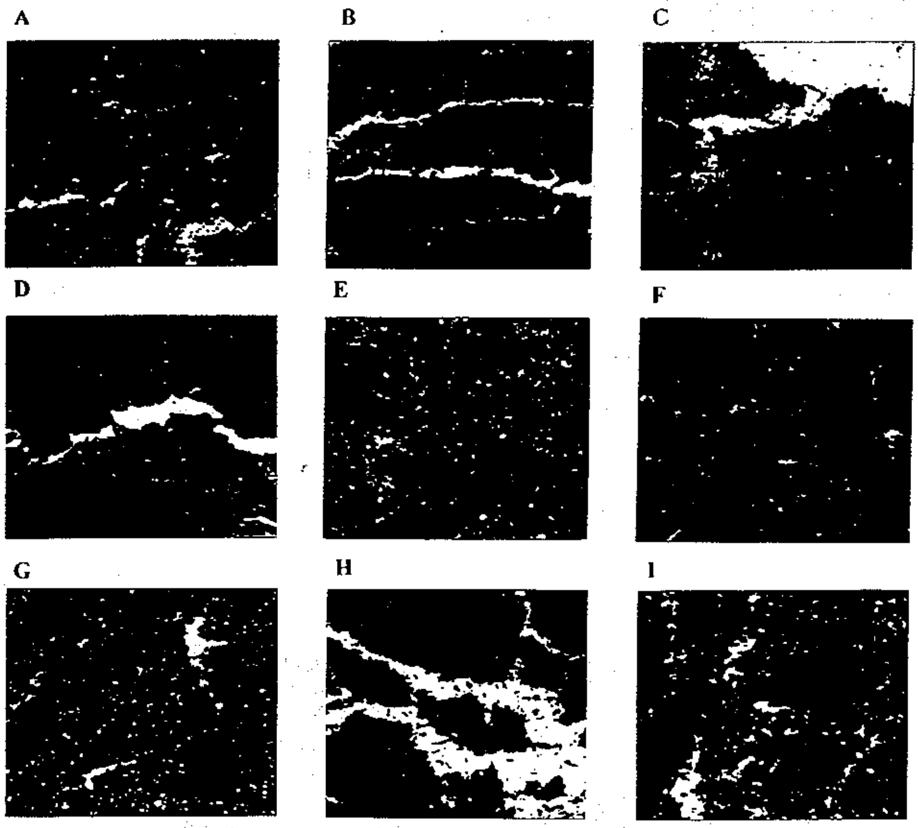


Fig. 3. The structure of the cultivated layer in the wheel-track left by a tractor. A. B. C. D. E. F. G. H. I- zones as in Fig. 1. Solid phase - black colour. pores - white colours

The results of number of pores measurements are difficult to be interpreted. Almost identical results were obtained for loose, uncompacted soil and for most compacted zone in wheel track (225 and 222), while the area of pores section was 26 times bigger in the first case above mentioned. This fact implies from the great differentiation of pores sizes. In more detailed analysis it will be necessary to classify the pores into smaller groups. The results obtained point undoubtly that the number of big pores decreases during the both: loosening and compacting of soil. The least difference between the number of pores >20 µm i <20 µm occured inside the aggregates taken from uncompacted soil (1:1.1), the highest in the zone F in wheel track (1:5.4), where the area of section of pores >20 µm was least.

CONCLUSIONS

1) The micromorphometric analysis has enabled to describe the location of zones with varying soil compaction in compacted soil layer.

2) The most compacted zone has been found in the wheel track at the depth 4-8 cm.

3) The most compacted zone has been characterized by the least total area of pores section, the least area of section of pores >20 µm and the highest ratio: number of pores <20 µm to number of pores >20 µm.

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A DAILY EMERGENCE DISTURBANCE INDEX FOR SUGARBEET BASED ON SOIL CRUSTING.

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ABSTRACT

Emergence of sugarbeet seedlings was studied under field conditions. Emergence rates and durations varied greatly. Irregularities in the emergence kinetics were associated with soil crusting. Crust formation and crust moisture status were taken into account through daily or cumulative rainfall thresholds. The average daily emergence rates were significantly different depending on the index. The effects of soil clay content and initial cloddiness were analysed separately.

INTRODUCTION

The success of a sugarbeet crop depends on uniform emergence dates and high emergence rates (1). Disturbance during crop establishment leads to variable growth during the early stages (2).

Soil crust affects the emergence of seedlings of several crops (3, 4, 5). Reduction of seedling emergence is due to the mechanical resistance of the soil crust to the emerging seedlings (6).

The emergence of sugarbeet seedlings was studied in Picardie in 1987 and 1988 in order to analyse the variations in emergence rate and duration under field conditions, and to describe the influence of the main physical and management factors.

MATERIAL AND METHODS

71 plots were studied. They were divided among field survey and experiments in which different sowing dates, soil textures, seedbed structures and sowing depths were compared. They provided a range of soils and sowing conditions (soil texture with 7.2-34.5 % clay content, soil tillage with various initial structural state for soil surface, seedbed physical conditions). The same commercial seed lot was used for all experiments. 7 or 14 mm artificial rainfall just after sowing was applied in order to create structural or sedimentary crusts (7) before seedlings emergence.

The total number of emerged seedlings, air temperature and rainfall were recorded daily. The final emergence rate (FER) was calculated as a percent of seed positions. Cumulated emergence rates (CER) were calculated for each emergence day as a percent of FER. Emergence duration (ED) was assessed as the number of days from the first emergence to CER = 0.9 * FER. Daily emergence rates (DER) were calculated as a percent of FER.

RESULTS AND DISCUSSION

Climatic conditions were favourable and the average FER for farm plots were very high (Mean 78.6% ; SD 9.4% ; Max 91.8% ; Min 53.1%). In some experiments where artificial rainfall was applied, FER decreased as a function of the crusting stage attained (Table 1).

Table 1 Final emergence rate (FER) in soil crusting trials.

	Morphological crusting stages			
	No crust	Discontinuous Structural Crust	Continuous Structural Crust	Depositional Crust
FER (%)	87.6	78.5	63.8	50.9

Emergence durations were very variable (Table 2).

Table 2 Emergence durations.

	Field Survey and Experiments			Growth Chamber	
	First Decile	Mean	Last Decile		
ED (days)	3.0	6.2	10.0	2.3	3.5
Mean temperature	14.6	13.8	13.1	15.0	10.0

The minimum values were consistent with growth chamber data (8), but total variability could not be explained by temperature alone. The distribution of emergence duration had a multimodal form (Figure 1).

Figure 1
EMERGENCE DURATION DISTRIBUTION

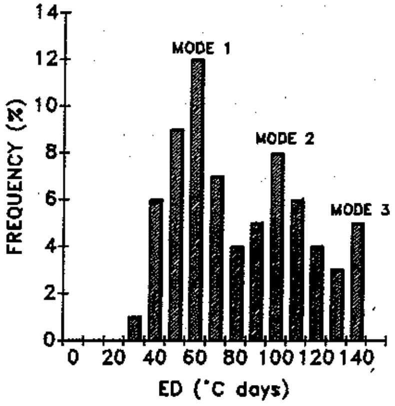
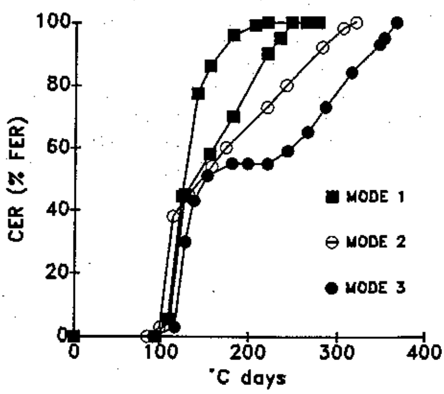
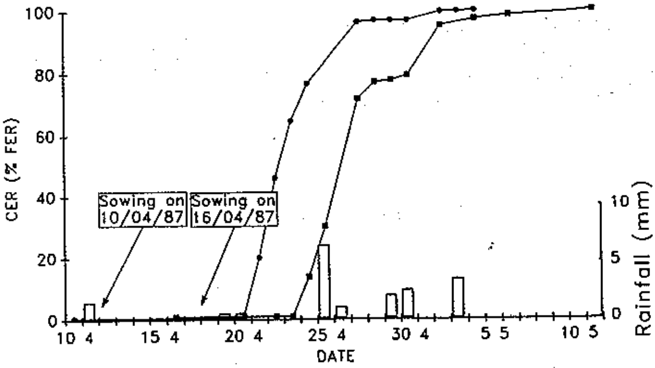


Figure 2
TYPICAL CURVES



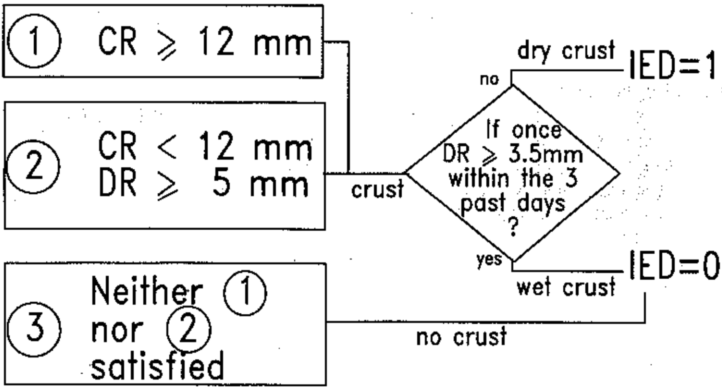
The modes of ED distribution were correlated with irregularities in the shape of the CER vs time curves (Figure 2). Mode 1 included undisturbed curves and curves with slighty reduced slopes, while mode 2 corresponded to a more intensive slope reduction. Curves with a plateau corresponding to an emergence break, were found in mode 3.
Analysis of some disturbed curves (Figure 3) could explain the physical mechanisms involved. A gap of 6 days between two sowing dates put these emergence kinetics in very different conditions considering the timing of rainfall and induced soil crust formation. A sharp decrease in DER was associated with a rainy period followed by soil surface dessiccation. Rewetting of the soil surface by a new rainfall induced a fresh increase in the emergence rate. The influence of these detrimental conditions on emergence duration were closely related to the period when rainfall occurred. The earlier rainfall appeared, the more numerous were the seedlings under crusts and the longer was ED.

Figure 3
DISTURBED CURVES



A daily index of emergence disturbance (IED) was developed (Figure 4). This indicator was based on threshold conditions for rainfall. Crust stages observed were related to cumulative rainfall (CR) from sowing day to examined day or to the occurrence of a daily rainfall (DR) >= 5mm during the same period.

Figure 4 Index of emergence disturbance.



The observed average daily emergence rates were significantly different according to IED value (Table 3).

Table 3 Average daily emergence rates

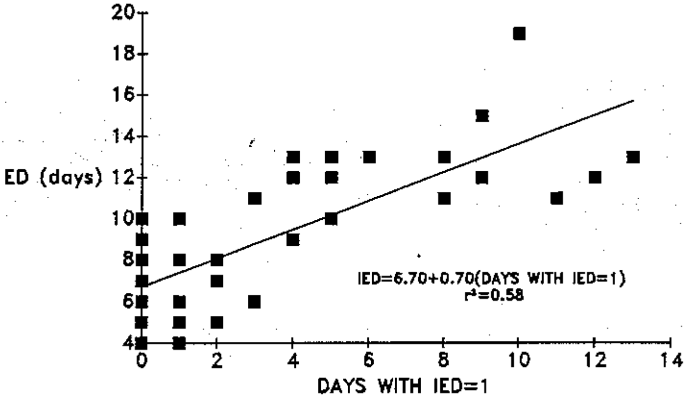
	DER		Sample size
IED	Mean	SD	
0	15.9	11.2	326
1	9.6	7.9	124

Soil crusting had a major effect on emergence rate and may affect seedlings and/or growth.

Effect of the number of days with an obstacle

If there was one or more days with IED=1 on a plot, ED was affected (Figure 5). An IED increase of 0.7 day was associated with each new day with IED=1. 58 % of ED variability was explained by the number of days with IED=1. Plot number was insufficient in order to explain residual variability.

Figure 5
ED VARIATION VS NUMBER OF DAYS WITH IED=1



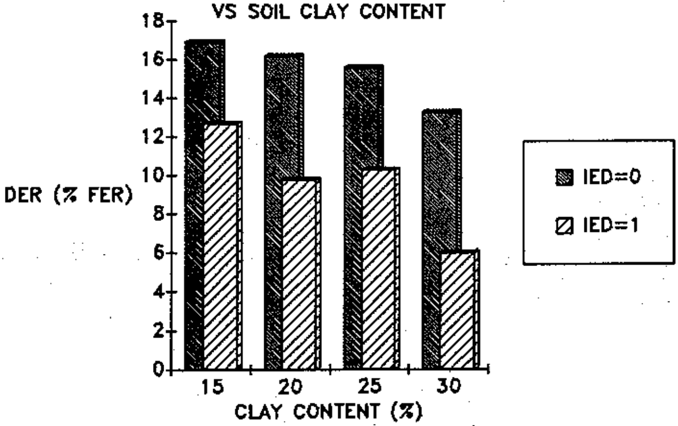
Effect of soil clay content

Soil clay content could have modified the DER response to IED via two opposite effects : reduction of the speed of soil crust formation by increase of aggreggates resistance, increase of soil crust strengh placed on the sugar beet seedlings.

If IED=0, average DER was slightly, but not significantly, decreased (Figure 6). If IED=1, DER was reduced with increasing clay content.

Considering the climatic conditions of the study, most rainfall occurred when the soil surface was dry. Therefore the major process of aggreggate breakdown was through slaking. In such conditions, the influence of soil cohesion is much less marked than under wet conditions (9). Therefore, the rate of soil crusting was not affected by soil clay content however crust strengh increased with increaseing of clay content.

Figure 6
DER VARIATION
VS SOIL CLAY CONTENT



Effect of initial cloddiness
The relationships between percentage of soil surface covered with aggreggates of different diameters and DER with IED=1, was studied. The finest structural state affected DER which was slightly, but not significantly, decreased. Crusts developed on rather cloddy soils, were visually less perceptible than for soils with fine aggreggates, but mechanical obstacle induced had the same effects considering seedling emergence.

CONCLUSION

Sugarbeet seedlings are very sensitive to mechanical obstacles. As a result, sugarbeet establishment is greatly influenced by soil crusting in the northern part of Paris Basin. Field studies like those reported here can help in the design of predictive models of sugar beet emergence (10).

Acknowledgements
The authors thank D. Boitez for technical assistance.

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TILLAGE IMPACTS ON C, N, AND P MINERALIZATION IN POULTRY LITTER AMENDED SOILS

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ABSTRACT

The effects of two years of tillage and soil amendment regimes on soil organic variables (organic C, N and P) and C, N and P mineralization/release were determined. Tillage systems investigated were strip (or conservation) and conventional tillage, with various soil nutrient amendments that included: no fertilizer, commercial fertilizer, and broiler litter. While there were no significant differences in soil organic C or N due to tillage/amendment management, organic P was higher in soils that had been conventionally tilled, as compared to strip-tillage. Carbon and N mineralization reflected the effects of prior tillage-fertility regime, and soils maintained under strip-till/broiler litter mineralized the greatest amount of C and N. Tillage also affected P release measured during the incubation study, where approximately 20% more inorganic P was released from strip-tilled soils than from those under conventional tillage. Results from this study indicate that relatively short-term agroecosystem management can significantly impact nutrient transformations and transfers within soil organic matter for a southeastern U.S. soil.

INTRODUCTION

In Alabama, and much of the southeastern U.S., a large and expanding broiler chicken (*Gallus gallus*) industry requires safe disposal of an enormous amount of waste, commonly referred to as broiler litter (manure and cellulose bedding material) (1). Broiler production has historically concentrated in upland areas where long-term disposal of litter to pastures has resulted in potentially adverse environmental impacts (2). Because litter has a relatively high nutrient content, the disposal problem could be solved, in large measure, by moving litter from broiler production areas to areas of intensive row crop production. Whereas the strong influence of tillage and soil nutrient amendments on ground and surface water quality is well established (3, 4, 5), the effects of these cultural practices on nutrient cycling in agroecosytems must be evaluated in order for application of broiler litter to cultivated soils to be a viable disposal option.

This study was conducted to examine C, N, and P mineralization/release in soils previously maintained for two yr under conventional or strip-tillage systems and commercial or broiler litter fertility regimes.

MATERIALS AND METHODS

Field setup and sample collection

The field site was located at the Alabama Experiment Station's Wiregrass Substation, Headland, AL (32° 24'N, 85°W). The soil was a Dothan fine-sandy loam (fine-loamy, silicious, thermic, Plinthic Paleudult). In 1990 and 1991, corn (*Zea mays* L.) was planted each spring on 90 cm row spacings. The experimental design consisted of four replications of two tillage systems in main plots and three fertilizer sources in sub-plots. The two tillage systems were conventional and strip (or conservation) tillage and the three fertilizer treatments were broiler litter, commercial fertilizer, and a control where no fertilizer was applied. The strip-till system, which is similar to no-till, employs a planter with a leading parabolic subsoiler (approximately 40 cm depth). Broiler litter was broadcast pre-plant at a rate of 9 Mg ha^{-1} on a fresh weight basis, and commercial fertilizer was applied at rates to match the total elemental content of N, P, K, and Zn in the broiler litter. This resulted in 2-yr total kg ha^{-1} applications for both broiler litter and commercial fertilizer of approximately 555 for N, 200 for P, 340 for K, and 3.0 for Zn.

On 28 March 1992 soil samples from the 0 to 10 cm depth increment were collected prior to tillage or fertilizer treatments. Soil organic C and total N were determined by dry combustion. Inorganic N was measured via standard colorimetric procedures (6). Soil organic N was calculated as the difference between total and inorganic N. Available P was measured in dilute double acid soil extracts (7). Soil organic P was determined as the difference in P from ignited and unignited samples (8).

Laboratory incubation study

Tillage and fertility management effects on C, N, and P mineralization/release were studied by laboratory incubation using the procedure of Nadelhoffer (9). From each tillage-fertilizer combination, subsamples from the field moist samples were weighed into microlysimeters for aerobic incubation in the dark at 25°C. The microlysimeters consist of upper and lower chambers fitted with ports that allow gas sampling from the upper chamber and collection of extracting solution from the lower chamber for determination of soluble ions. Concentration of CO_2 was measured on samples obtained from the upper chambers which was then injected into an infrared gas analyzer (LI-6251 CO_2 Analyzer, LI-COR Inc., Lincoln, NE). Microbial mineralization of inorganic N and release of inorganic P were determined by equilibrating soil samples in the upper chamber with 0.01 *M* $CaCl_2$ then drawing the extractant through filters into the lower chamber where it was collected for analysis. Measurement of CO_2 respiration rates, N mineralization, and P release were made following initiation of incubation at 1, 3, 5, 7, and 10 days, weekly through day 35, and every other week through day 254. Modeling cumulative mineralization or release was performed by regression of cumulative C, N, or P and time (days).

RESULTS AND DISCUSSION

Soil organic matter from field setup

There were no significant effects due to either tillage or soil amendment regimes for soil organic C and double acid extractable P (Table 1). For soils maintained under conventional tillage, we observed a slight trend (Prob. = 0.13) toward higher concentrations of soil organic N as compared to strip-till (Table 1). Conventional tillage also resulted in an average of approximately 60% greater concentrations of soil organic P than for strip-till (Table 1). We suggest that the higher soil organic P concentrations observed under conventional as compared to strip tillage may be manifestation of available P from amendments and crop residues, supplied to a larger portion of the soil microbial population and subsequent incorporation into biomass.

Laboratory incubation

Microbial respiration of CO_2 during the 254-day incubation furnished evidence of varying C substrate quality owing to field treatments insomuch as organic C concentrations for pre-incubated soils were not different (Tables 1), while C mineralization was influenced by tillage and fertilizer regimen (Figure 1). The highest cumulative C mineralization value was associated with broiler litter under strip tillage and the lowest was with conventionally tilled soils where no amendment was applied (Figure 1). Carbon mineralization results for these two treatments make intuitive sense though they could not have been predicted from measurements of soil organic C alone. Also, cumulative mineralized C was 33% higher for strip tillage than conventional where broiler litter was applied.

As with microbial respiration, N mineralization during laboratory incubation reflected the influence of previous tillage-fertilizer practices (Figure 1). For example, the greatest cumulative N mineralization occurred in soils maintained under strip-till and amended with broiler litter, which was similar to the outcome obtained for C mineralization, and was approximately 47% greater than N mineralized from soils where broiler litter was applied under conventional tillage (Figure 1). These results imply that even though two yr of conventional tillage had likely promoted slightly larger total soil organic N concentrations (Table 1), strip till management may have resulted in a larger labile N fraction.

Approximately 0.4 mg kg^{-1} more inorganic P was released during the 254-day incubation from strip-till as compared to conventionally tilled soils (Figure 1). In addition, two yr of prior soil amendments had differential effects on cumulative P released (Figure 1). Greater cumulative P was released from both commercially fertilized and broiler litter amended soils than from soils receiving no fertilizer. Commercial fertilizer and broiler litter-P applications promoted a larger pool of easily extractable P (0.01 *M* $CaCl_2$ extractant) than was found in control plots despite similar double-acid extractable P levels in pre-incubated soils (Table 1).

CONCLUSION

These results provide evidence that organic matter processes in a southeastern U.S. soil can be influenced by relatively short duration agroecosystem management. It has been demonstrated that the quantity of ions potentially mobilized via microbial activity cannot be predicted from measurement of total concentrations alone. The impact of agroecosystem management on the quantity and quality of nutrient pools must be considered in order to insure environmentally sound utilization of organic materials such as poultry waste.

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Table 1. Mean concentration of soil organic C and N and extractable and organic P as affected by 2 years of either conventional or strip tillage and either broiler litter or commercial fertilizer applications at Headland, AL.

Treatment		Organic C	Organic N	Extractable P	Organic P
Tillage	Amendment	------------g kg^{-1} soil--------		----------mg kg^{-1}----------	
Strip	Control	4.1(0.3)†	0.37(0.1)	43(5.8)	42(4.6)
Strip	Commercial	4.4(0.5)	0.34(0.6)	54(5.1)	50(12.6)
Strip	Broiler Litter	4.0(0.3)	0.39(0.0)	53(7.8)	54(11.1)
Conventional	Control	3.7(0.1)	0.45(0.05)	46(5.9)	70(3.8)
Conventional	Commercial	3.8(0.2)	0.47(0.02)	48(3.7)	71(1.6)
Conventional	Broiler Litter	4.2(0.3)	0.37(0.02)	47(5.7)	93(16.6)
Tillage§					
Strip		4.1(0.2)	0.37(0.03)	50(3.7)	49(5.5) b‡
Conventional		3.9(0.1)	0.43(0.02)	47(2.7)	78(5.0) a
Amendment¶					
Control		3.9(0.2)	0.40(0.04)	44(3.9)	56(6.1)
Commercial		4.1(0.2)	0.41(0.04)	51(3.1)	59(8.0)
Broiler Litter		4.1(0.2)	0.38(0.01)	50(4.6)	71(11.6)

†Standard error of the mean. ‡Means followed by the same letter did not differ at the 0.1 level of significance using the Bonferroni method; variables with no letters were non-significant. §Means averaged across all soil amendment treatments. ¶Means averaged across all tillage treatments.

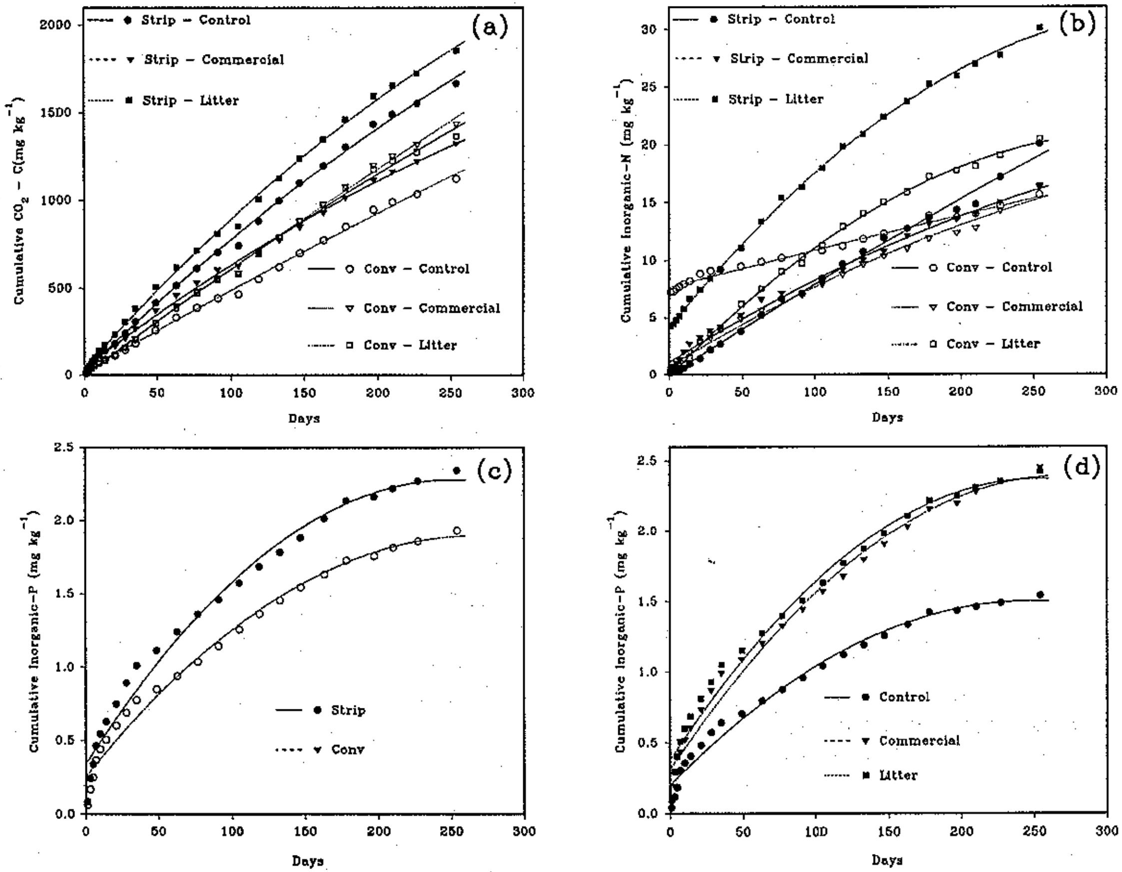

Figure 1. Cumulative C mineralization (a), N mineralization (b), and P release (c and d) during incubation as affected by tillage and soil amendment.

SOIL PHYSICAL STATUS CHANGES AS INFLUENCED BY LOSSES OF AVAILABLE ORGANIC CARBON

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ABSTRACT

The changes of water retention (at pressures of 0, 5, 30, 100 kPa), strong-adsorbed water content, group humus composition and hydrophilic specific surface area were determined after long-term mineralization of available organic C by thermophilic microorganisms in meadow-brown and podzolic soils. Values of CO_2 and N_2O emission from meadow-brown soil samples were measured by flame pbotometric detector for a gas chromatograph. On the basis of tbese results, values of emission ratio Ce/Ne and coefficients of relative availability of soil organic C (CRAC) were calculated for meadow-brown soil samples taken from plots corresponding to cereals, corn, meliot, soyabean.

INTRODUCTION

Exact operative evaluation and prognosis of soil physical status and organic C balance are needed under conditions of systematic agricultural use of soils. At the present time, the dry and wet combustion methods are used for determining the soil organic C balance (1,2,3). Firstly, these methods do not allow to conduct exact measurements of total C content because of imperfect oxidation of organic matter, and secondly, to separate a total C content according to a degree of its availability. Besides, an evaluation of changes of physical status of soils influenced by wet combustion of organic C is impossible because a treatment of soil by different chemical compounds leads to irreversible changes of composition and properties of soil solid phase (4). Few data are reported on the non-chemical and non-destructive methods of quick evaluating the balance of soil organic C differing in its availability for mineralization by soil microflora (5,6). In our present study the advanced methods of conjugate determinations of soil available N and organic C contents, and a procedure of removal of soil available organic C by thermophilic microflora at high temperature were used (7,8). The objectives of our study were to: (1) determine the soil available organic C and N contents in clay loam meadow-brown soil; (2) investigate an influence of removal of available organic C by thermophilic microorganisms on group humus composition and physical status of meadow-brown and podzolic soils.

MATERIALS AND METHODS

Soil sampling

Disturbed samples of clay loam meadow-brown soil were collected from the 0-20-cm depth on rotation plots consisting of cereals, corn, meliot and soyabean. Disturbed samples of loamy sand podzolic soil were taken from the 0-20-cm depth of non-tilled plot. All air-dried soil samples were passed through 2-mm sieve.

Chemical, biological and hydrophysical properties of soils
Total C content in soils was determined by wet combustion according to Tjurin's procedure before and after soil incubation (3). Humin, humic and fulvic acid (HA and FA) contents were measured by Ponomarjova's and Plotnikova's procedure (3).

For conjugate measuring the CO_2 and N_2O emission the air-dried samples (10 g) of meadow-brown soil were moistened to 60% of saturation (at pressure of 0 kPa) and packed into glass vessels (50 cubic cm). Soil incubation was conducted at 28° C for 7 days (aerobic conditions) and at 36° C for 4-10 days (anaerobic conditions). Regularly,during both mentioned periods the CO_2 and N_2O evolution was measured by flame photometric detector. Values of Ce/Ne ratio were calculated as a proportion of total CO_2 and N_2O emission amounts.

For determination of available organic C the moistened samples (60% of saturation) of meadow-brown soil were packed into glass vessels (50 cubic cm), and incubated at 65° C for 60 days. Measurements of CO_2 emission were regularly performed by gas chromatograph using flame photometric detector.

Values of CRAC were calculated according the following formula: CRAC = (C-CO_2 /(C-CO_2) + Cr)×100%, where C-CO_2 - total CO_2 emission amount; Cr - residual content of weakly available C measured by the Tjurin's procedure. Values of sum of C-CO_2 and Cr indicate a partly measured and calculated content of total C.

To determine the influence of losses of available organic C on soil physical properties, air-dried samples of meadow-brown and podzolic soils were moistened to 60% of saturation and incubated in glass vessels (1000 cubic cm) at 65° C for 60 and 360 days, respectively.

Water retention of these samples was measured by pressure-plate apparatus at 25° C and pressures of 0, 5, 30, 100 kPa. Values of hydrophilic specific surface area (at 25° C in the absorbtion regime) and strong-adsorbed water content with simultaneous dry combustion of organic matter at 230° C were determined on the basis of procedures developed at the Agrophysical Research Institute (9,10).

RESULTS AND DISCUSSION

Carbon and nitrogen emission
Results of measurements of C-CO_2 and N-N_2O emission showed different availability of organic C and N in meadow-brown soil. Values of C-CO_2 and N-N_2O emission from meadow-brown soil samples taken from the fields corresponding to cereals, meliot, corn, soyabean, corn were: 360, 1070, 2090, 920, 840 mg/kg and 0,1, 34, 15, 30, 18 mg/kg.

Values of CRAC for meadow-brown soil on the same plots were: 4,3; 12,8; 16,5; 4,9; 15,1%, respectively. On the basis of these results and those of calculations of Ce/Ne ratio, the fertility levels of plots corresponding to cereals and corn (third plot) were low and high, respectively. Values of Ce/Ne for soil samples collected from the fields corresponding to cereals, meliot, corn, soyabean, corn were: 3600; 31,5; 13,9; 30,7; 46,7. Optimal values of CRAC and Ce/Ne ratio must reach 10-15% and 10-20. In general, these values correspond to the fertility conditions on the corn plots.

Results of determinations of content of easily available organic C (Cav) based on the C-CO_2 emission, and the contents of weakly available and total C shown in Table 1 suggested the above-mentioned conclusions on the fertility levels of plots of meadow-brown soil. At relatively high total C content measured before incubation, the easily available organic C content in meadow-brown soil from the plot corresponding to cereals was the lowest. These results suggested the advantages of separation of total C content into the easily and weakly components using procedure of removal of available organic C by thermophilic microflora.

Changes of total carbon, group humus composition, and physical status of soils

Results of determinations and calculations of parameters of group humus composition and the properties of soil water are shown in Tables 1, 2, 3

Table 1 Group humus composition, total (Ctot), easily (Cav), and weakly (Cr) organic C contents before/after incubation of clay loam meadow-brown soil at 65° C for 60 days.

Treatment	HA	FA % of Ctot	Humin	Ctot %	Cav %	Cr %
Cereals	50,8/41,8	43,1/54,0	6,1/4,2	3,11	0,13	2,87
Meliot	51,9/38,0	44,2/49,4	3,8/8,2	2,87	0,39	2,69
Corn	50,1/38,0	38,7/44,4	11,2/17,6	3,75	0,65	3,29
Soyabean	52,2/26,2	44,0/55,1	3,7/18,7	2,68	0,39	2,25
Corn	49,2/31,6	46,9/52,8	3,8/15,6	2,62	0,36	2,12

Losses of available organic C from meadow-brown soil lead to the considerable decrease of HA content and the increase of FA and humin contents. Among the selected treatments, the lower decrease of HA content was observed in the soil samples taken from plot corresponding to cereals because of the lowest content of available organic C. Thermophilic microorganisms during incubation of meadow-brow soil samples caused the decrease of humin content in samples collected from the plot corresponding to cereals.

Results of measurements of the BET model parameters (monolayer water content, Wm, and energetic constant, Cm), and maximal hygroscopity (MH), strong-adsorbed water content (SAW), losses of organic matter (LOM) at 230° C are presented in Table 2.

Table 2 Water properties and organic matter content before/after incubation of meadow-brown soil at 65° C for 60 days.

Treatment	Wm %	Cm	MH %	SAW %	LOM %
Cereals	1,92/1,58	42,86/57,43	7,99/6,79	-0,88/-0,83	2,57/2,63
Meliot	1,85/1,53	44,45/38,40	7,74/7,04	-0,86/-0,77	2,55/2,31
Corn	2,00/1,68	48,98/45,32	7,96/7,12	-0,91/-0,82	3,75/3,29
Soyabean	2,01/1,71	31,41/30,61	8,07/7,36	-0,88/-0,80	2,08/1,86
Corn	1,99/1,72	32,29/27,51	7,98/7,41	-0,87/-0,77	2,10/1,91

Monolayer and strong-adsorbed water contents, and maximal hygroscopity values demonstrated the decrease after the removal of available organic C by thermophilic microorganisms from soil in all treatments. Values of energetic constant as a characteristic of heterogenity degree of solid phase surface increased in treatments with cereals and decreased in other treatments. The same trend was observed in the case of losses of organic matter by dry combustion at 230° C. Values of hydrophilic specific surface area calculated by means of the values of monolayer water content (Wm x 36,14) decreased from 67-72 to 55-62 m^2/g and from 16 to 5 m^2/g as a result of microbiological incubation of meadow-brown and podzolic soils, respectively.

Values of total C content and energetic constant of podzolic soil decreased from 1,46 to 0,15% and from 172 to 56 after incubation during 360 days. These results showed essential increase of hydrophobity of surface of solid phase of both soils after mineralization of available organic C.

Results of measurements of water retention of soils at 25° C are presented in Table 3.

Table 3 Mean values of water retention properties of meadow-brown and podzolic soils before/after incubation at 65° C for 60 and 360 days.

Treatment	Pressure (kPa)			
	0	5	30	100
	Water retention			
	% of weight	% of volume		
Meadow-brown soil				
Cereals	70,1/68,9	61,2/46,4	50,4/42,5	33,2/40,4
Meliot	69,7/66,4	56,6/51,0	45,0/44,4	33,9/44,2
Corn	70,8/69,6	64,5/48,0	51,3/45,5	38,9/44,1
Soyabean	63,5/66,0	53,7/46,0	47,3/44,4	36,8/38,6
Corn	61,5/64,1	52,5/48,2	44,7/45,7	35,3/33,5
Podzolic soil	64,5/37,3	23,5/19,9	14,6/10,7	11,7/8,8

Mineralization of available organic C by thermophilic microorganisms results in changes of water retention properties which are widely being used for describing the soil physical status.
The changes of water retention of clay loam meadow-brown soil were mainly caused by changes of microaggregate-size distribution and pore geometry structure. Water retention of this soil decreased at low pressures (5-30 kPa) and increased at higher pressures (100 kPa) because of formation of system of smaller pores.

Increase of the hydrophobity of surface of solid phase of podzolic soil played main role in considerable decreasing the water retention at selected pressures.

Values of coefficients of correlation for the selected parameters of organic matter and water status of meadow-brown soil are provided in Table 4. Results of correlation analysis indicated that the lowest coefficients of correlation were observed for relationships between the CO_2 emission and water retention at 0,30 kPa, and losses of organic matter (at 230° C) and water retention at pressure 0 kPa, respectively.

Table 4 Coefficients of correlaton for relationships between selected parameters of organic matter and water status of meadow-brown soil after incubation at 65° C during 60 days.

Parameter	Adsorbed water				Capillary water	
	SAW	Wm	Cm	MH	30 kPa	0 kPa
$C\text{-}CO_2$ emission	-0,72	0,44	-0,63	0,45	0,03	-0,09
Ctot content	0,46	-0,98	0,44	-0,63	-0,59	-0,94
LOM	0,84	-0,59	0,93	-0,88	-0,63	-0,25
Humin content	-0,37	0,79	-0,54	0,79	0,88	0,81

CONCLUSIONS

This study demonstrated that microbiological removal of soil available organic C lead to considerable changes of parameters of physical status of meadow-brown and podzolic soils. The proposed methods give an good opportunity of evaluation of available C and N contents in soils as influenced by different factors.

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THE INFLUENCE OF CRUSHED STONES ON PHYSICAL PROPERTIES OF SOIL ARABLE LAYER

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INTRODUCTION

As was said by an ancient philosopher Plinius: what hampers for work - is not necessarily harmful for yield. The discussion among the researchers and farmers deals with the eternal question: what limit of soil stoniness is harmful, when it cause some benefits for crops. It was determined that stones in light sandy soils reduced crop yield and had a contrary effect on heavy soils (4). Picking of stones from the fields where crops demanding porouse environment were grown (potatoes) noticably reduced tuber yield and quality (6,7). At least three ways of stony fields cleaning exist now: picking, burying in subsoil and crushing. The trials in Lithuania have shown that stone crushing is more effective, in terms of crop yield and total labour costs of field reclamation, than picking and removal from arable fields (1).
With the view to study comprehensively the effect of crushed stones (CS) on soil properties and crop response experiments were conducted in Lithuania Moraine Plane on loamy soil.
The effect of stones (as well as crushed) in soil generrally is defined by the extent they change:

a) the volume of fine earth of arable layer;
b) the potential and direct soil nutrient balance;
c) physical quality of root growth environment.

Main emphasis of this article is put on the findings which account for their physical effect on the soil.

MATERIALS AND METHODS

The objects of study were:

- crushed stones 20-30 mm in diameter;
- soils of different types with the different rate 0, 175, 350, 525 m^3/ha (or 0, 7, 14, 21 % by volume of arable layer) and origin of crushed stones in soil arable layer;
- system: STONES — SOIL — CROPS

and interaction of those elements.
One field trial as well as two microplot (1x1 m) were conducted with the aim to investigate the influence of CS on physical, chemical properties of soil and crop yield.
Pot experiments with the strict control of CS rate in soil,

soil moisture content as well as bulk density were carried out too.
The technology of stone (average 10 cm in diameter) crushing has been used in field experiment, where different rates 0, 175, 350, 525, m^3/ha typical for Lithuanian Middle Plain stones were crushed by means of a stone crusher IK-1,2, designed in the Lithuanian Institute of Agricultural Engineering . Afterwards they were mixed with the fine earth of arable layer.Plots under four replicates were designed randomly.
Soil for bulk density measurement was sampled by means of cylinders (1327 cm^3) with 8 replicates after harvesting. Special for stony soils methodic was used for the other calculations of physical values (8,9). Soil structure was determined by Savinov method (8). Soil moisture content by oven drying mode, mostly during soil bulk density establishing. Stone moisture capacity- by formerly used State standards: Gost 7025-54b 5219-50 and 8209-56. Soil moisture infiltration rate- by means of laboratory equipment UVF-1 (5 replicates). Stony soil moisture evaporation was measured using pot method. Heat capacity of separate stones (5-25 cm in diameter) and stony soil with the various rate of CS as well as albedo of soil surface were determined with the soil thermometers, device JU-116 and calculations applied in heat physics. Annual frost action for single stones movement in different depth of soil profile (60 units 5-25 cm in diameter) was determined by means of precise +1 mm levelling.
The trial were laid on soddy podzolic gleyey soil with the organic matter content 3,2 %, pH 7,4. Textural analysis has shown particles < 0,01 mm- 26,3 %, > 0,01 mm- 69,8 %. Background stoniness of an experimental site was 3,0 % by volume (stone size 3-30 mm).

RESULTS AND DISCUSSIONS

Effect of CS on soil bulk density, porosity and structure
Phycical indices of fine earth by CS were affected more significantly than the entire stony soil (table 1). The bulk

Table 1 Effect of crushed stones (CS) on soil physical properties. Average of 4 years (1986-1989).

CS m^3/ha	%	Bulk density g/cm^{-3}		Ratio: water to air	Porosity Total %		Aeration %	
		Fine earth	Stony soil	Fine earth	Fine earth	Stony soil	Fine earth	Stony soil
0	0	1,50	1,50	1,60	42,4	42,6	17,5	17,5
175	7	1,43	1,48	1,25	43,0	45,3	20,2	21,2
350	14	1,40	1,52	1,17	42,1	46,2	20,5	22,5
525	21	1,36	1,53	1,00	42,0	48,0	22,0	24,9
LSD.95		0,033	0,033	0,174	1.31	1.33	1,75	1,72

density of fine earth decreased by 0,14 g/cm^{-3} with the increase of CS from 0 to 525 m^3/ha. The difference between stony soil and the fine earth bulk densities in case of stone rate 525 m^3/ha was determined 0,17 g/cm^{-3} and it is caused by the influence of CS.

Total pore space content was found similar both in stony and stone-free soil- at an average 42%. But porosity of fine earth in stony soil (525 m^3/ha) was found by 11 percentage units greater. With the increase of CS rate in soil, porosity of aeration increased up to 30 percentage units. So, CS in soil function as soil loosening measure. It is important in loamy soils which are prone to overcompaction. Presence of stones in soil even 525 m^3/ha exerts favourable influence upon all grown crops there.

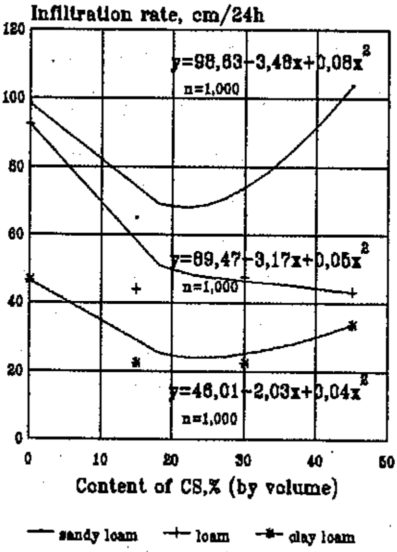
The structure of stony soil (fine earth) was not significantly altered by the action of different rate of CS. But the coefficient of structuriness indicated evident decreasing of structural aggregates smaller than 0,25 mm with the increasing of CS content in soil.

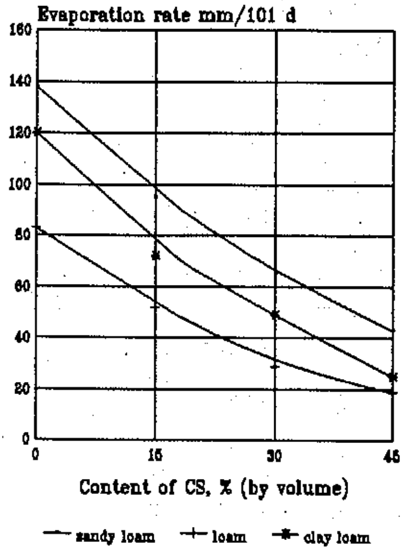
Moisture mobility in stony soil

It was determined that moisture storage capacity of CS (as rocks of different origin) is quite small: Magmatic, metamorphic- 0,70-3,44 %, for sedimentary- 4,50 %.

It is obvious that water storage capacity of stony soil always is less than of stone-free one. We found that difference is usually 1-3 %. Water mobility both up and down direction in stony soil was rather complicated under the presence of CS (figure 1). In case of equal part of fine earth in all

Figure 1 Water infiltration and evaporation rates in stony soil (1988).



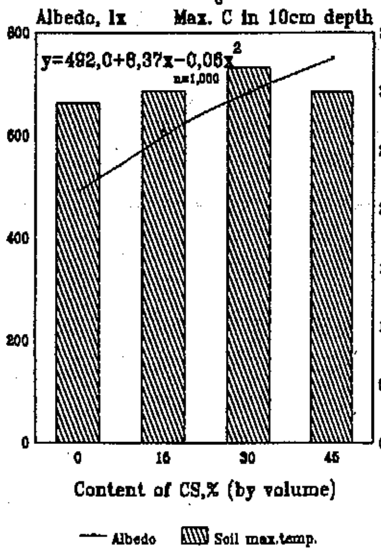


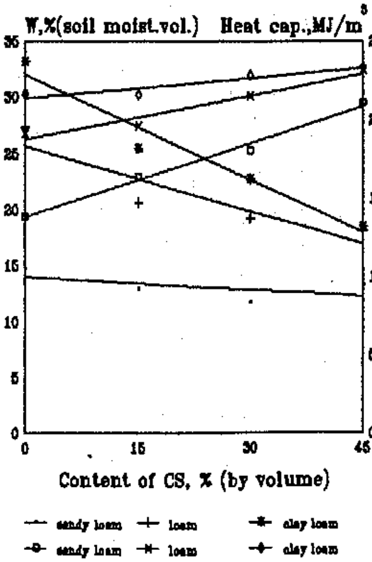
the treatments, CS rate 0-15 % by volume acted as a measure decreasing water infiltration rate in all soil texture types. Stone content 30-45 % notably increased infiltration rate close to the initially stated values. Such findings were partly confirmed in soil moisture evaporation experiment (figure 1), where we stated that in all the scale of stoniness, evaporation rate decreased by 26-83 %. Stone surfacing rate was found generally not significant for moisture evaporation rate when the total soil was stony.
We hope that such phenomenon are occasioned due to the pecularity of stones to colmotate and destroy the network as well as function of vertical capillaries. So, water flow becomes especially curvilinear and therefore slow. Simillar results were observed in field conditions after rain too. The literature, as regards especially water movement in stony soil, are quite contradictory (1,2,5). Most of references deal with data confirming that stones increase water mobility, but other focus upon soil textural peculiarities as a basic factor (5).

Heat regime of stony soil and frost action

Crushed stones of various origin exert influence on soil heat properties as thermomulch, especially when stone rate increases more than 30%. Stone surfacing rate from 0 up to 60% increased light reflection from 492 lx to 749 lx (60 % of CS). CS promote heat inflow into the soil up to 30 % of CS was in soil. The reflection of light and heat prevail over the inflow, in case of greater soil stoniness than 30 % (figure 2). Daily temperature fluctuation 1,0-1,7 ^{0}C was more contrasted in stony (60 % of CS).
As the heat capacity (HC) mainly depends on soil texture and moisture content, evident differences of heat distribution were found in drier or lighter soil. As shown in figure 2 the

Figure 2 The effect of crushed stones (CS) on soil surface, albedo, max. temperature in 10cm depth and heat capacity (1988).





HC of drier stony sandy loam soil was higher by 52 %. In both stony loam and clay loam HC has increased by 8-21 %.
Annually observations of stone altitudes have shown that frost action (both pull and push) strongly affected upwards by for a couple of centimetres in the beginning of freezing season and downwards in spring. Most of their "returned" to the former place (high) on the beginning of summer. After the five year measurements we came to the conclusion that stones were more sensitive to frost action and irreversible lifted by 3 mm, when they by 1/4 of their surface have had contact with the atmosphere and were placed in the arable layer of soil. As regards widespread saying "stones are growing", it seems to be mutual action both by frost and soil tillage implements.

CONCLUSION

The affect of crushed stones in loamy soils can be described generally as action of physical body, but at the same time, can not be separated from the chemical influence if the origin of stones is sedimentary.
Crushed stones maintain soil in looser conditions during all the growth period, therefore loamy stony soils, prone to overcompaction can be improved by means of stone crushing and leaving in arable layer.
Water mobility in stony soil mainly depends on the quantity of stones. Infiltration rate has decreased when CS rate was 0-15 % and increase was established in case of 30-45 % of CS.
Soil moisture evaporation content was found significantly lesser (26-83%) in stony soils of different texture.
Soil daily temperature fluctuations by 1,0-1,7 ^{0}C were higher contrasted in stony soil.
As was determined all these physical changes under the action of crushed stones, influenced positively (4-10 %) crops yield.

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MASS TRANSFER IN CHERNOZEM, GREY FOREST AND SOD-ALLUVIAL SOILS UNDER AGRICULTURAL USE

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ABSTRACT

The relation of the convective-dispersive mass transport (CDM) on soil structure was studied. It has been shown the spatial variability of soil structure characteristics were affected the CDM model parameters. The CDM coefficient D_* and effective pore volume depended on the filtration rate.

INTRODUCTION

The functioning of the natural and agricultural landscapes depend on water transport and dissolved nutrient substances. The study of the mass transport is important to develop of the adequate and optimal doses of the fertilizers and elucidate of the mechanisms of soil and subsoil pollution. There are a few information on spatial variability of the CDM characteristics. On the other hand the hydrodynamics dispersion have been often studied on disturbed soil samples. This work have been done to estimate of the spatial variability of the CDM parameters and their dependence on the soil structure. The soil pore space structure have been also considered as soil structure characteristics.

MATERIALS AND METHODS

The experiments were carried out on the undisturbed soil cores of the Grey Forest, Sod-Alluvial soil and Chernozem. The Grey Forest soil cores were sampled from the plot 12 m in length and 9 m in width. The Sod-Alluvial had a vary particle-size composition: sandy, loamy sand and loamy. Morphological differences from the three profiles of Typical Chernozem were described. The experimental plot and all profiles studied were chosen at the fields under agricultural use. A special sampler was used to paraffinized of the lateral face of the sample at the time of sampling. Undisturbed soil cores 10 cm height and 5 cm in diameter from the $A_{horizon}$ were placed into the device in which the filtration rate was controlled by a peristaltic pump. Different solutions of calcium chloride were filtered through the samples. The chloride ion used as a label was measured by a direct potentiometry using chloride selective electrodes OP 17116 (Radelkis, Hungary). To obtain pF-curves, soil cores 4,5 cm in diameter and 4 cm height were placed subsequently into the cells with suction pressure from -0.5 to 50kPa. The effective pore radius distribution was calculated from the relation between the sample moisture content and suction pressure using Jurin's formula (1). Effective pore volume was estimate from the breakthrough curve (2). Two models were used to determine convective - dispersive parameters. Model I did not take into account a stagnant zone of the soil pore volume and model II assumed its existence.

RESULTS AND DISCUSSION

The parameters of the CDM model were determinated both for the model I and for the model II as well. If even one parameter in either of the model did not differ significantly from zero, the model was unacceptable, the one that fit the data better was chosen by the William criterion (3). For the sixteen Grey Forest soil cores in about half of the cases model II fit the data better then model I. This situation had not previously been encountered: the same model had been used to process the data from all the samples collected from the same plot. However, the textural characteristics of the samples can give rise to differences in the course of the convective-dispersive model.

Biggar and Nielsen found the value of D_* measured in the field were log-normal distributed (4). The log-normal distribution of the CDM coefficient D_* obtained with model I and model II was observed in our experiments (Fig. 1).

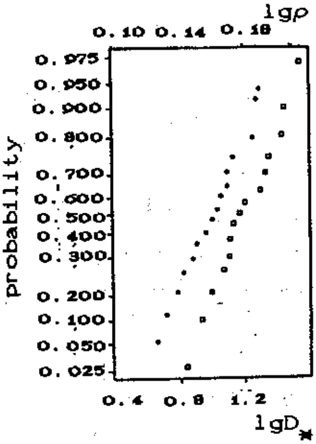

Fig. 1. Spatial distribution function: □ - CDM coeficient D_* and ■ - bulk density ρ for the Grey Forest soil plot.

It should be underline that variability of the parameters in the CDM model where non - instantaneous mass exchange between the stagnant and moving zones is assumed has not previously been studied. A bulk density value was also log-normal distributed. For the most of the Chernozem and Sod-Alluvial soil cores the model II was unacceptable. Probably, the differences in the pore space structure characteristics of the samples may led to the differences on the acceptability of the CDM model. The pore size distribution curve for the Chernozem and Sod-Alluvial soil had a distinct maximum in macropores with r > 0.06 mm, and for the Chernozem, profile 1, maximum shifted to the range of the cracks with r > 1mm (Fig. 2). It can be assumed that in the soil pore space with macropores mass exchange occurs primarily in large pores, a bulk of small pores almost did not take park in the mass exchange process. Thin pores do not take part in the mass exchange processes. If there are some cracks in pore space the bypass flow may occur and weakly (Cl^-, NO_3^-) and strong sorbed substances (pesticides) move deeply in the soil profile and accumulate in lower horizons (5). In that case mass transport has mainly occur in cracks and the participation of small pores is very limited.

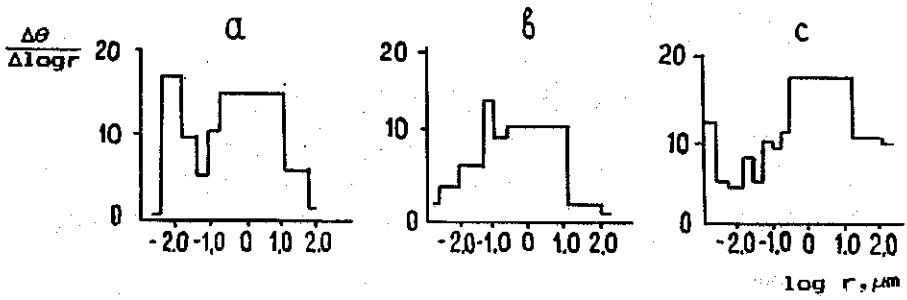

Fig. 2. Pore radius distribution curves; (a) - Chernozem, profile 3, (b) - Sod-Alluvial loamy sand soil, (c) - Chernozem , profile 1.

The filtration rate does not affect the D_* distribution. The power dependence between D_* and V have been observed for the undisturbed soil cores $D_* \sim V$, where n ranged from 1.0 to 1.6 for different soils (6,7). Similar dependence was observed on the different soil studied. For example, for the samples of the Grey Forest soil studied n was equal 1.36, at the filtration rate ranged from 1.5 to 12.3 cm/day. For the Sod-Alluvial soil with different texture at the range of the filtration rate from 0.15 to 10.4 cm/day n was changed from 1.0 to 1.4 and for the Chernozem n was changed from 1.25 to 1.54 at the filtration rate changes from 1.0 to 11.7 cm/day. The maximum value was observed for samples with the largest bulk density. The value of the effective pore volume, V_e, decreases considerably with an increase in the filtration rate (Fig. 3).

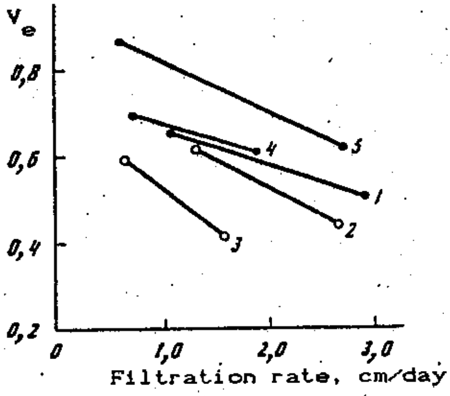

Fig. 3. The relation of effective pore volume V_e to the filtration rate: (1)-(3) Typical Chernozem, Profile 1-3, respectively; (4), (5) Sod-Alluvial loamy and loamy sand.

The character of the change in V_e has determined by pore space structure. For example, in the presence of macropores $dV_e/dV \approx -0.2$, in their absence $dV_e/dV \approx -0.1$ over filtration rates ranging from 0.5 to 3 cm/day.

CONCLUSION

Mass transport characteristics in undisturbed soil cores studied was significantly affected by the pore space structure.

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CRITICAL PENETROMETER RESISTANCE FOR ROOT GROWTH IN SOILS

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ABSTRACT

This paper examines both published and new information on the penetrometer resistance (PR) and bulk densities at which root growth is minimum (critical) for a wide range of soils in order to find a general explanation in terms of the compressive behaviour of soils. Results show that a general decline in critical bulk density and critical penetrometer resistance (CPR) with clay content may be due to a non-linear increase in compression index of soils with increase in clay content. Despite difficulties associated with the detailed measurements on the configuration of voids which commensurate with the dimensions of probes and roots, results of a laboratory study indicate that the CPR is likely to decrease in soils with increase in number of voids because of lower soil confinement in the radial direction of probes and roots.

INTRODUCTION

Tillage is commonly used to improve soil structure and to reduce soil resistance to root penetration. In certain situations tillage may be aimed at reducing soil mechanical stress to roots alone, for instance in soils which have root-impenetrable zone in the subsoil. As tillage is expensive, correct decisions on the depth and frequency of tillage is required. Experience shows that penetrometer measurement can be an useful aid in making decisions on tillage.

Managers of farms, orchards and plantations often deal with a wide range of sites and climates and require a simple and reasonably accurate concept based on easily measurable soil properties to help decisions on tillage. Consideration of a single value of penetrometer resistance as a critical, upper limit (for a particular situation) has considerable appeal. There is no *a priori* reason that the CPR will be the same for all types of soils and a wide range of plants. A number of field and laboratory studies show that root growth stops or approaches a low level when the soil has a maximum penetrometer resistance (e.g. 4 and 19). Since there is considerable variation in the types of penetrometers and their usage, it is difficult to compare published values of critical penetrometer resistance (18). Despite the lack of a standard practice in penetrometer measurements, it is possible and indeed worthwhile to examine the merits and mechanical basis of the CPR concept. The purpose of this paper is to examine published and unpublished information in support of the CPR concept and the variation in CPR with respect to presence of voids and channels in soil, large enough to accommodate probes and roots.

VALIDITY OF CPR CONCEPT

The ways root tips and penetrometer probes deform soil, and the mechanical properties of soil which allows soil to resist such deformation are reasonably well understood (1, 2, 12 and 13). However, the theories used to explain the mechanisms of root and probe penetration are complex and require tideous and expensive measurements. Thus some simplification of these theories (without loss of generality) are needed to obtain useful parameters relating to the physical interaction between soil and roots (16).

Soil is compressed in the radial direction of the root or the probe tip during penetration, although the shapes of the compression zones may differ. If a soil sample is subjected to uniaxial stress, it can be shown that soil can be compressed only to a finite extent. Further compression is not possible with increase in stress beyond this limit (1 and 6). The bulk density corresponding to this limit value of stress may be theoretically taken as a conservative estimate of the critical bulk density to which a soil can be compressed because root growth may stop well before the soil reaches such a high bulk density. If a soil has been compressed to this bulk density due to natural processes or traffic, neither roots nor metal probes should be able to penetrate the soil. As soil is heterogeneous and the mechanical properties of roots vary considerably, roots may take advantage of cracks, fissures and channels in soil and will continue to grow. In situations where the soil is deficient in the pockets of low strength, root growth may stop well before the critical bulk density of soil is reached. As compressibility (derived from the uniaxial stress-strain measurements) allows description of the bulk of the mechanical behaviour of soil under measured applied stress, it is reasonable to consider the compressibility of the soil than the limit to which a soil can be compressed. Here and in what follows, compressibility (or compression index as in 6) is defined as a unit change in bulk density for a logarthmic increment in stress as follows:

$$C_i = (\rho - \rho_k) / [\log_{10}(\sigma/\sigma_k), \qquad (1)$$

where C_i is the compression index (Mg m^{-3} MPa^{-1}), ρ and ρ_k bulk densities (Mg m^{-3}), and σ and σ_k are corresponding applied normal stresses (MPa). Equation (1) shows that for a constant increment of applied stress, a soil of high C_i will be compressed to a higher bulk density than a soil of low C_i.

An alternative approach to quantify CPR is to obtain the maximum possible pressure which roots can exert in the axial direction (3, 5 and 14) and find the corresponding penetrometer pressure. This approach is useful in modeling of root growth (e.g., 17). However, direct measurement of axial pressure exerted by roots (8, 13 and 20) is tideous and may vary with plant age (14) and other environmental conditions. Therefore, this approach will not be pursued further in this paper.

RESULTS AND DISCUSSION

Mechanical basis of CPR

Measurements of bulk density around pea roots and conical metal probes (2) show a general decline in bulk density from a maximum (which occurs at or adjacent to the root/probe surface) with increase in radial distance from the root and probe surfaces. This decrease in bulk density can be represented by an equation of the type (16).

$$\rho(r) = \rho_{max} - (\rho_{max} - \rho_i)\left[1 - e^{C_i\left(\frac{r-r_0}{r_0}\right)}\right], \qquad (2)$$

where $\rho(r)$ is the bulk density at a radial distance r from the root or probe, ρ_{max} and ρ_i respectively the maximum and initial bulk densities and r_0 is the radius of the root or probe. In this equation C_i is used instead of the constant k used previously (16). Note that the densities ρ_{max} and ρ_i, and the exponent C_i are independent of r and are assumed as constants for a soil. The analysis of Dexter (16) showed k to be 0.34 for roots which is not very different from the C_i values for the same soil (calculated from 1). Similar calculations made for the sharp probes (3 mm dia and 30° conical tip) and blunt probes (3 mm dia and 60° conical tip) for the present analysis indicated that both sharp probes and roots have $k \cong C_i$ whereas k was somewhat greater than the C_i for blunt probes. The discrepancy in the k value from C_i in the latter case may have been due to the difference in the mode of deformation for the blunt probe from that of sharp probes and roots.

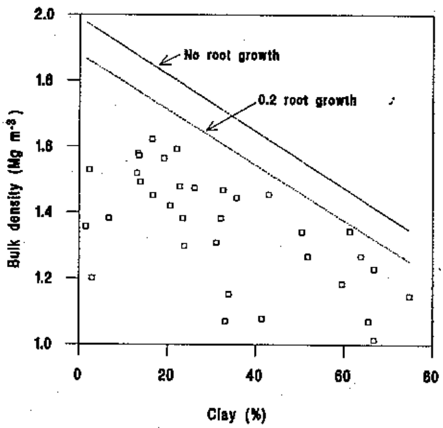

Fig. 1. The relationship between the critical bulk density and clay content of soil. The lines represent the bulk densities at which no root growth or 0.2 of maximum root growth is possible. The data points show the bulk density (ρ_{max}) estimated from publsihed data (6) with equation (3).

The assumption of $k=C_i$ permits a general use of the solution of equation (2) to find the maximum bulk density to which a given soil can be compressed by the root. The solution of equation (2) is

$$\rho_{max} = \rho_i\left(1 + \frac{1}{2q(q+1)}\right) = \rho_i\left[\frac{(C_i+1)^2+1}{2(C_i+1)}\right], \qquad (3)$$

where q is the reciprocal of C_i. Calculations of ρ_{max} from published data on C_i (6) is shown in Fig. 1 for a range of soils with varying amounts of clay. Also shown are the critical bulk densities at which root growth decreases to 0.2 of the maximum or at which no root growth can occur (from the data in 9). This figure shows a linear decline in critical bulk densities with increase in clay content and the line for 0.2 of the maximum root growth is an upper limit to the estimates of ρ_{max}. The initial bulk densities (ρ_i) assumed in these calculations were those measured at a standard pressure of 0.1 MPa (6). If the initial bulk density of the soil is higher than those used here, the calculated ρ_{max} will well exceed the values of critical bulk densities reported in the literature and hence, roots will not be able to penetrate such compacted soils. Thus the calculated values of ρ_{max} shown here corroborate the findings of Jones (9).

As the general effect of C_i on the critical bulk density is less obvious from Fig. 1, general relationships between ρ_i and C_i with the amount of clay were sought by fitting following empirical equations to the data in (6).

$$C_i = 0.187 + 0.182 \log_{10} x, \qquad (r^2=0.58, n=34) \qquad (4)$$

and

$$\rho_i = 1.453 - 0.006\, x, \qquad (r^2=0.49, n=34) \qquad (5)$$

where x refers to the clay content (%) of the soil.

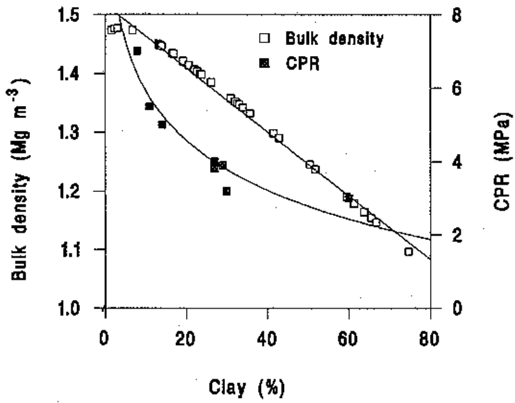

Fig. 2. Bulk density (ρ_{max}) and CPR as functions of the amount of clay in soil.

Fig. 2 shows a plot of the resultant relationship between ρ_{max} and clay content. Also shown is the critical penetrometer resistance, i.e. CPR (measured with a 3.5 mm dia, 60° conical probe) as a function of the clay content (7). This figure shows a nonlinear decrease in CPR and a linear decrease in ρ_{max} with increased clay content of the soil. Clay soils have higher compression index and hence pose greater difficulty for root penetration than sandy soils. This explains the reason for clay soils to have lower CPR than the sandy soils. It should be noted that most of the data (7) represent a linear decrease in CPR with increase in clay content up to 30%. The non-linearity of the fitted curve is mainly due to the value of CPR at 60% clay.

Effects of voids on CPR

It is common in many field and laboratory studies to measure PR on soils or sites which are relatively uniform and free from large voids, cracks and holes. Although the distribution of these voids can be measured (10 and 15), the exact configuration of the voids in relation to the site of penetrometer measurement is not generally known. Voids and aggregates in a soil can be detected with fine penetrometer probes (11). However, it is not yet clear whether the penetrometer measurements can provide some indication of the distance to the nearest void. The effect of the presence of a void some distance away from the path of the penetrometer probe may be considered similar as the effects of the variation in diameters of probes and aggregates on the PR (12). Fig. 3 shows PR as a function of the radial distance (r') from the edge of the aggregates. The PR of a probe passing through a void larger than its diameter is obviously zero. The data in Fig. 3 show that there is likely to be a considerable reduction in PR for a probe when the probe is psuhed close to the edge of a void due to inadequate soil confinement in the radial direction of the tip. As the radial distance from the edge of the void increases, PR essentially increases to a maximum and further increase in distance from the void should have little influence on the PR. The influence of voids on the CPR is anticipated to be similar to that for the PR shown in Fig. 3. Thus with increase in the number of voids of diameters similar to roots and fine probes, CPR is likely to decrease as the likelihood of soil confinement in the radial direction of the probe is small.

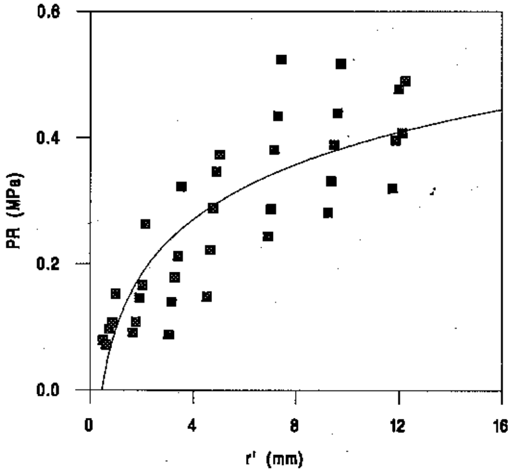

Fig. 3. The relationship between penetrometer resistance (PR) with the radial distance from the edge of aggregate (r') for a range of probe and aggregate diameters (Unpublished data, Misra, 1986). Each of the data point in this graph represents the mean of 10 replicate measurements on PR.

CONCLUSIONS

The results presented in this paper demonstrate the possible effects of the compression index (obtained from independent measurements) on the compression characteristics of soil adjacent to roots. The information on the bulk density to which soils of widely varying texture can be compressed by roots from an initial bulk density is important in making decisions on tillage until better information becomes available. However, there are experimental difficulties in obtaining accurate, quantitative information on the 3-dimensional distribution of voids in soil and in estimating the sensitivities of penetrometers and probes to presence of these voids. Further experimental work will be needed to test a wide application of the mechanical basis of

CPR presented in this paper, in particular, the relationship between CPR and the compression index.

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EVALUATION OF CONVENTIONAL AND MINIMUM TILLAGE EFFECTS ON WINTER BARLEY (*Hordeum vulgare* L.) IN A SANDY SOIL.

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ABSTRACT

A six year (1986-1991) study based on the comparison between conventional (CT) (25-30 cm deep ploughing) and minimum tillage (MT) (10-15 cm deep disk harrowing) was carried out in south-west Tuscany on a very sandy soil. The results showed that soil penetrability in the 0-30 cm soil layers was lower in the ploughed plots with respect to the plots treated with MT. As the years passed, the barley root system became more poor and shallow when treated with MT than when treated with CT. CT allowed for higher grain yields especially when the water deficit was not high during the ripening stage. This difference was less evident when high evaporative demand and low rainfall occurred.

INTRODUCTION

Soil tillage reduction is necessary to conserve soil fertility and to save time and energy. In this respect, the results of several studies - carried out by the authors in the evaluation of the mechanical and energetical characteristics of the work chains used for conventional and minimum tillage - outlined the economical advantage (due to cost reduction) and the higher time efficiency of minimum tillage with respect to conventional tillage (1)(2). This is very important in Italy where the ploughing depth is usually quite high: 45-55 cm for spring-summer crops in silty and clay-like soils and 25-30 cm for winter cereals in sandy soils. These types of soils are characterized by a low organic matter and nutrient content and by a very low water retention capacity. They are generally unable to provide farmers with adequate incomes when conventionally cultivated with open ground herbaceous crops. Moreover, on some sandy soil, tillage is needed to reach an adequate structural state for root growth and water and gas flux (3)(4). Sandy soils, which cannot naturally structure themselves, need deep tillage which will in turn allow for higher yields improving physical characteristics (5)(3). This effect has not always been confirmed (6)(7)(8). For these reasons, in Italy there is also a clear need to study the feasibility of replacing conventional tillage techniques with those of reduced tillage.

MATERIALS AND METHODS

A field experiment was carried out on sandy soil at the Interdepartmental Centre for Agronomic-Environmental Research of the University of Pisa from 1986 to 1991 on level ground where rye was previously grown (tab.1). The techniques of minimum tillage (10-15 cm deep disk harrowing - MT) and conventional tillage (mouldboard ploughing 25-30 cm deep - CT) were tested from 1986 to 1988 on a rapeseed/barley rotation and from 1989 to 1991 on a rye/barley rotation carried out in space and time. Previous crop residues were always buried in the soil.

Table 1 Physical, mechanical and chemical characteristics of the soil, as observed in 1986.

Horizons (cm)		0-15	15-30
Sand (2-0.02 mm)	(%)	87.3	7.5
Silt (0.02-0.002 mm)	(%)	5.5	5.3
Clay (<0.002 mm)	(%)	7.2	7.2
Soil type (USDA classification)		Typic Xeropsamments	
pH		5.3	5.4
Organic carbon	(%)	0.87	0.82
Total N	(%)	0.086	0.081
C/N ratio		10.45	10.15
Phosphorus (assimilable)	(μg/g)	81.25	72.62
Potassium (exchangeable)	(μg/g)	52.62	45.75
C.E.C.	(meq/100g)	6.30	5.92
Field capacity (-1/3 bar)	(% vol.)	15.2	
Wilting point (-15 bar)	(% vol.)	5.5	

Winter barley (cv.Arma) was sown on 26.10.1985, 2.12.1986, 16.11.1987, 6.12.1988, 11.11.1989 and 9.11.1990. All tillage treatments received 110 $kg\cdot ha^{-1}$ of N and 60 $kg\cdot ha^{-1}$ of P. In different periods of the crop cycle, soil penetration resistance was measured between 0 and 70 cm in scales of 5 cm with a penetrograph (manual "Stiboka" tool equipped with a 1 cm^2 surface area cone). The root density and distribution of barley were determined from 0 to 60 cm in depth, in scales of 15 cm, during the ripening stage. Three sub-samples have been collected from each plot and processed according to a well tested methodology (9)(10). Grain and biomass yields were determined on a 6 m^2 test area at the ripening stage. The main yield components were evaluated on a 1 m^2 area. A randomized complete block experimental design with four replications was used. The data of the physical characteristics of the soil and of the barley root system were processed according to a "split-block" scheme (11)(12).
The differences between rainfall and evaporation observed during the test period are shown in table 2.

Table 2 Differences between rainfall and evaporation during the testing period.

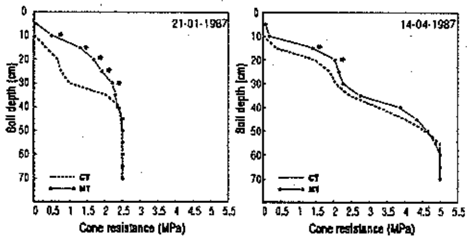
Months	X	XI	XII	I	II	III	IV	V	VI
1985-86	-34	106	122	95	71	37	43	-147	- 81
1986-87	-60	201	58	96	55	-56	-41	-79	-117
1987-88	227	153	33	59	0	-25	24	12	- 45
1988-89	68	45	24	2	16	-31	95	-115	- 88
1989-90	-21	64	26	19	11	-23	101	-140	-126
1990-91	-155	148	121	-11	15	-15	-60	- 10	- 85

RESULTS AND DISCUSSION

Cone resistance

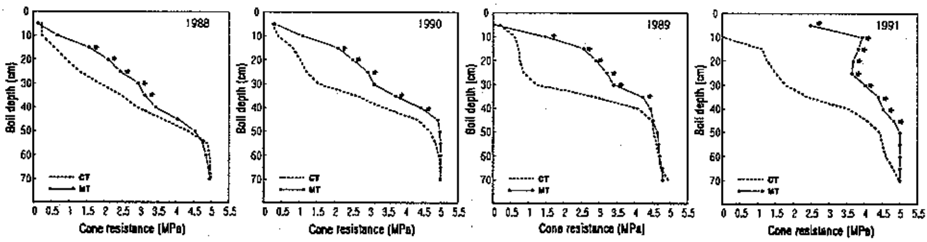
Cone resistance was measured from 1987 to 1991 when water content in soil from 0 to 60 cm was similar (ranging from 15.0 % in 1987 to 13.1 % in 1991 on the average). In 1987, two observations were made in January and April (with a level of soil water content of 16.6% and 15.0% respectively) (fig.1).

Fig.1 Soil penetration resistance in 1987 (values quoted with [*] are statistically different at .05 probability level).



The cone resistance data in the 10-35 cm soil layers was higher when the MT technique was used than when ploughing was conducted. This fact was more relevant in January when the differences between CT and MT were statistically significant from the topsoil (10 cm) to the lowest limit of ploughing (30 cm). On the other hand in April the difference was significant only in the 15-20 cm soil layer. This could indicate a quicker soil settlement in CT with respect to MT conditions. As a matter of fact, from January to April, the average resistance results in the 5-30 cm soil layer increased from 0.46 MPa to 0.70 MPa in CT (+52%) and from 1.28 MPa to 1.34 MPa in MT (+5%). The results obtained in the following testing years confirm that CT can make soil penetrability lower than MT in the layer between 15 and 30 cm of depth (fig 2).

Fig.2 Soil penetration resistance in the tested period (values quoted with [*] are statistically different at .05 probability level).



The average data of cone resistance measured in MT in the 0-30 cm soil layer generally increased during the testing years as shown in table 3.

Table 3 Cone resistance (MPa) in the 0-30 cm soil layer during the testing years.

Years	1987	1989	1991	1988	1990
CT	0.70	0.73	1.16	0.86	0.88
MT	1.34	2.26	3.60	1.64	2.01
LSD .05		0.48		n.s.	

LSD values must be used to compare CT and MT means only under the same row

The comparison between the results obtained from the same plots where observations were made (1987-1989-1991 in one instance and 1988 and 1990 in the other) points out a progressive worsening of this soil characteristic when continuous MT is conducted on the same plots. On the contrary, the results of cone resistance in CT seem to be characterized by a very low fluctuation in the testing period .

Root system

The root dry matter of barley was higher under CT with respect to MT in the 0-15 cm, 15-30 cm and 30-45 cm soil layers with the passing of time (tab.4).

Table 4 Barley root density (D.M mg dm^{-3}) in the tested soil layers.

Years	Soil layers (cm) 0-15		15-30		30-45		45-60		
	CT	MT	CT	MT	CT	MT	CT	MT	$LSD_{.05}$*
1986	764	610	340	379	269	238	101	90	n.s.
1987	524	586	329	257	194	133	37	114	n.s.
1988	748	826	477	303	137	71	9	13	n.s.
1989	503	317	326	122	161	103	14	8	65
1990	578	573	454	220	336	39	35	26	97
1991	617	319	361	132	255	40	28	4	127

* For each year, LSD values must be used to compare CT and MT means only under the same layer

As a matter of fact the outcomes of CT and MT were statistically significant only in 1989, 1990 and 1991. No significant difference was observed in the deeper layer (45-60 cm). The data of the whole root dry matter determined in the tested section (0-60 cm) was processed in order to perform an analysis over years after testing the homogeneity of error variances derived from the individual analyses of the variance (12) (tab.5).

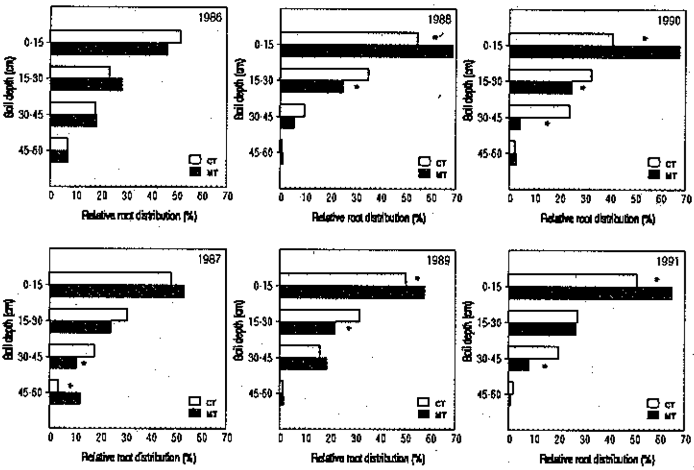
Table 5 Barley root density (D.M. mg dm^{-3}) in the 0-60 cm soil layer

Years	1986	1988	1990	1987	1989	1991
CT	368	343	351	271	251	315
MT	343	303	215	273	138	124
$LSD_{.05}$		71			94	

LSD values must be used to compare CT and MT means only under the same row.

The application of this analysis, outlined that the barley root density in the 0-60 cm soil layer decreased a under MT condition in the last three years. The relative root distribution was calculated as the percent ratio of the root dry matter determined in a given layer of soil and the whole root system dry matter observed in the tested soil section (0-60 cm) (fig.3). In all the tested years, with the exception of the first one (1986), the increases of the portion of the root system displaced in the most superficial soil layer (0-15 cm) were significantly higher in MT than in CT.

Fig.3 Relative root distribution of winter barley in each one of the soil layers as percentage of the whole root system (values quoted with [*] are statistically different at .05 probability level).



The relevant difference between the results obtained in 1986 and in the other testing years could be caused by the effect of the original, pre-experiment ploughing carried out on the experimental field, as shown in table 4. This is true for all the other soil layers. In the deeper layers (15-30 cm and 30-45 cm) CT induced a higher root concentration with respect to MT. These results show that the root system of barley had increasing difficulties in penetrating the soil as the years went by in the plots under MT.

Crop yields

Grain and biomass production of winter barley under MT technique were always lower with respect to CT technique in the testing period (Tab.6).

Table 6 Yields (D.M.) and grain yield components of barley.

Years	Plants ($n.m^{-2}$)		Ears ($n.m^{-2}$)		Grain ($g.m^{-2}$)		Straw ($g.m^{-2}$)		Total ($g.m^{-2}$)		Weeds ($g.m^{-2}$)	
	CT	MT	CT	MT	CT	MT	CT	MT	CT	MT	CT	MT
1986	224a	218a	324a	258b	325a	245b	311a	230b	636a	475b	31a	86b
1987	281b	305a	356a	341a	291a	274a	265a	284a	556a	558a	1a	4a
1988	200a	188a	476a	409b	445a	367b	307a	274a	752a	641b	6a	31b
1989	275a	244a	463a	445a	454a	350b	376a	331b	830a	681b	11a	50b
1990	258a	220a	385a	332b	390a	276b	355a	302b	745a	578b	6a	56b
1991	173a	215b	268a	280a	304a	283a	257a	215a	561a	498a	15a	34b

Values not followed be common letters are statistically different at .05 probability level.

The average reduction of grain yield in the six year period was about 18%, but it was varied each year according to the climatic conditions. As a matter of fact, in 1987 and 1991, when the water deficit (rainfall-ET) was high in April, the difference between CT and MT yields was rather low (-6 and -7% respectively). In these years, when a high evaporative demand and a low rainfall occurred, the low differences between CT and MT grain yield seemed to be related to the reduction of soil water availability in the ploughed soil (6)(13). On the contrary, in 1989 and 1990, with the absence of relevant soil moisture problems, the yields of barley were significantly higher in CT than in MT: therefore the differences were greater (+30% and +41% respectively). The higher grain yields were associated with an increase of ears per square meter and thousand-grain weights observed in the ploughed plots. The lower grain yield obtained in the first year (1986) in MT seems also to be related to a higher presence of weeds.

CONCLUSIONS

In the tested sandy soils, the repeated adoption of superficial tillage (six years of disk harrowing in this case) caused a relevant increase in soil penetration resistance and a progressive worsening of the environment for root growth. Consequently the development and the arrangement of root system under minimum tillage were modified as the years went by resulting in increasingly more poor and more shallow in the last three years. On the contrary mouldboard ploughing enhanced root growth of barley by reducing soil cone resistance and stabilizing it during the testing years. The adoption of CT also caused an increase of grain yield by augmenting the number of fertile ears per unit area and thousand-grain weights. These results were less evident when high evaporative demand and low rainfall occurred.

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TILLAGE BELOW THE SEED HASTENS THE EMERGENCE OF WHEAT SEEDLINGS ON A HARDSETTING SOIL - THE CAUSES AND THE IMPLICATIONS FOR DIRECT-DRILLING.

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ABSTRACT

A field experiment investigated the effect of tilled and untilled soil below the seed on the emergence of wheat *(Triticum aestivum* L.) seedlings on a hardsetting soil at Tatura, Victoria, Australia. Soil physical properties of the seedbed including penetrometer resistance, temperature and water content were recorded. The fate of seeds and seedlings and the length of roots were determined. Germination was high (>90%) and was not affected by the depth of tillage, or by temporary water logging, but several physical properties of the soil restricted emergence. The rate and final emergence (at day 10) was increased by tillage below the seed (e.g. 46-90 mm depth) in spite of the penetrometer resistance of soil at 0-20 mm depth being 50% greater than that in the treatment untilled below the seed. The roots of the seedlings in the treatments untilled below the seed were temporarily waterlogged (at days 0-1) and grew in soil that was drier (at day 3-9) and harder than in treatments tilled below the seed. Tillage below the seed increased the rate of emergence by decreasing the penetrometer resistance of the soil to less than 2.0 MPa.

INTRODUCTION

Emergence of wheat *(Triticum aestivum* L.) seedlings is poor (<63% of seeds sown emerge) on hardsetting Red-brown Earths in south-eastern Australia (McLeod, unpublished results, 1986). The importance of this phase of growth has largely been ignored because tillering of plants was thought to compensate for poor emergence. This assumption is questionable, since reduced rates of emergence have been correlated with lower yields of grain (1). Therefore, for maximum yields of grain, high populations of wheat seedlings (>100 plants m^{-2}, (2) are needed. We report on a field experiment that showed that traditional systems of direct drilling stressed the roots of unemerged seedlings and decreased emergence.

MATERIALS AND METHODS

The experiment was performed on Lemnos loam, a Naterxalf (3) or Red-brown Earth (Dr 2.33, (4), at the Institute for Sustainable Agriculture, Tatura, Victoria, Australia (36° 26'S, 145° 16'E). The soil consisted of about 150 mm of loam overlying a massive clay (5). Fine sand, silt, clay and organic carbon of the top 100 mm of soil consisted of 300, 350, 350 and 11 g kg^{-1} respectively. pH of the 1:5 soil:water suspension was 5.9 and the soil was potentially dispersive (6). The soil was also in class 3 of the Emerson (7) test i.e., the soil slaked but only dispersed when remoulded. The lower plastic limit of the soil was 0.20 kg kg^{-1}. In each of the two years prior to these experiments, wheat was direct drilled, harvested and the residue retained as a mulch on the soil surface. The experiment was conducted in April, which is a usual time for sowing cereal crops in this region.

To test the hypothesis that 'emergence was decreased when roots of seedlings grew in untilled soil' a strip rotary-hoe tilled the soil at either 0-45 mm or 0-90 mm depth and at the same time a precision seeder sowed the seed at 45 mm depth (8). Each treatment was replicated 10 times to make a total of 20 plots. In each plot, a single row of wheat *(Triticum aestivum* L. c.v. Rosella) was sown at 40 seeds (>3 mm diameter) m^{-1} into soil with a water content of 0.13 kg kg^{-1}. After the crop was sown, all plots were irrigated (4 mm) by micro-jet sprays at an intensity of 12 mm h^{-1}, then a molluscicide ("Defender" 4 g m^{-1}, active ingredient metaldehyde) was sprinkled over the sowing-line to prevent damage from slugs (Gastropoda: Plumonata). Rain (12 mm) fell 12 h later.

Penetrometer resistance of soil along the sowing-line was measured on days 4 and 7 after sowing. A data logger linked to a 2 mm diameter probe (60° included angle), moving at 1.1 mm s^{-1} recorded the penetrometer resistance of soil every second from 0-90 mm depth. This was done at three random positions along the middle of the sowing-line in each plot and the mean penetrometer resistance at each depth was calculated. Temperature was measured every 0.25 h throughout each experiment along the sowing-line in each plot at the depth of the seed. The gravimetric water content of the soil was measured along the sowing-line at 10.00 h on the sowing date and on each of the next 9 days. Soil 80 mm x 50 mm width at 0-45 mm and at 46-90 mm depth in each plot was sampled for gravimetric water content.

On days 3 and 10 after sowing the fate of seeds, and on day 3 the fate of seedlings recovered from a 1-m length of the sowing-line was determined. The seeds were scored as germinated (radicle 1-5 mm long), ungerminated (radicle <1 mm long) or damaged (cracked and/or black). The seedlings were scored as emerged (coleoptile visible at the soil surface), obstructed (seed germinated but coleoptile prevented from reaching the soil surface by hard soil) or unemerged (seed germinated with unobstructed coleoptile yet to reach the soil surface). In addition, the number of emerged seedlings was also measured each day after the first seedling had emerged on another 1-m length of the sowing-line. All measurements were expressed as a percentage of the total number of seeds recovered from the respective 1-m length of the sowing-line. The total length of roots on the seedlings excavated at day 3 and scored for fate of seeds was also measured.

The experiments were in a randomized block design. The results for fate of seeds and seedlings were analysed with a generalized linear model using logit-link function for binomial error distribution. We used an analysis of variance with a normal error distribution for the other results (Genstat 5. Rothamsted Experimental Station).

RESULTS

Soil Measurements

During the experiment the soil in all treatments became harder; at day 4, mean penetrometer resistance (0-90 mm depth) was 1.0 MPa and at day 7 it was 1.8 MPa (Fig.1; Fig.2). The soil (0-90 mm depth) probably became harder because it had dried from 0.18 to 0.15 kg kg^{-1}. These results support those of Dexter (9) who showed that the hardness of a Red-brown Earth from the Waite Institute doubled for every 2.5% decrease in gravimetric water content. A crust that had formed by day 7 was evident from the increased penetrometer resistance near the soil surface (Fig. 2). The soil at 0-20 mm depth (including a crust which had developed at 2 mm depth) was about 50% harder in the treatment tilled 0-90 mm than in the treatment tilled 0-45 mm (Fig. 1; Fig. 2). The soil at 46-90 mm was more than twice as hard in the treatment tilled 0-45 mm (i.e. untilled soil) than in the treatment tilled 0-90 mm (tilled soil) (Fig. 1; Fig. 2)

The mean daily temperature at the depth of seed on each day during the first week of the experiment was about 1°C higher ($P<0.05$) in the treatment tilled 0-45 mm compared with the treatment tilled 0-90 mm (not shown here). In both treatments the maximum daily temperature at days 1-10 ranged from 23-30°C, and the minimum daily temperature ranged from 12-16°C. These temperatures were all within the suitable range for the growth of wheat seedlings (10). In the treatment tilled 0-45 mm, coleoptiles began emerging after 116°C days (i.e., the sum of mean daily temperature from the day that the crop was sown to the day that the first coleoptile emerged), while in the treatment tilled 0-90 mm coleoptiles began emerging after 110°C days ($P<0.05$). Emergence was delayed from the 95-100°C days suggested by Malse and Passioura (11) as typical for wheat in the absence of water stress.

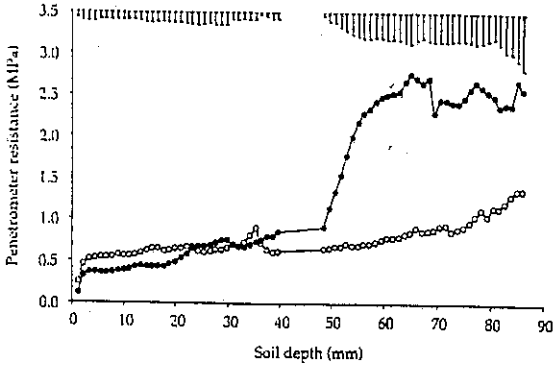

Fig. 1. Penetrometer resistance of soil tilled to 0-45 mm (closed symbols) and tilled to 0-90 mm (open symbols) at day 4 (error bars; l.s.d., n=60, P<0.05)

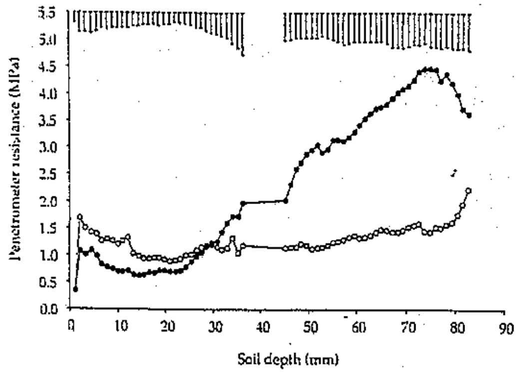

Fig. 2. Penetrometer resistance of soil tilled to 0-45 mm (closed symbols) and tilled to 0-90 mm (open symbols) at day 7 (error bars; l.s.d., n=60, P<0.05)

The water content of soil 0-45 mm depth did not differ between treatments during the experiment (not shown here). In both treatments, the soil 0-45 mm depth was wetter than field capacity (0.23 kg kg^{-1}) at days 1-2, then the soil dried to a water content of 0.14 kg kg^{-1} at day 9. Due to the heavy rain just after the crop was sown, the soil 46-90 mm depth in both treatments was wetter than field capacity at days 1-2, and by day 9 the soil had dried to a mean water content of 0.16 kg kg^{-1} (Fig. 3). At each of days 3-9, the soil at 46-90 mm depth was wetter in the treatment tilled 0-90 than the treatment tilled 0-45 mm (Fig. 3). Free water, 10 mm deep was seen at the bottom of the tilled layer in both treatments. This was not shown in the results of gravimetric water content as the sampling procedure failed to collect all the free water.

Plant measurements

Neither the percentage of germinated nor the percentage of damaged seeds differed between the treatments at day 3 or at day 10 (not shown here). In each treatment 90% of all seeds had germinated at day 10 and a mean of 4% were damaged. Differences in percentage emerged seedlings were accounted for by the percentage of unemerged and obstructed seedlings (Table 1). About one third less seedlings had emerged in the treatment tilled 0-45 mm than those tilled 0-90 mm at days 6-10 (Fig. 4). Final percentage emerged seedlings (at day 10)

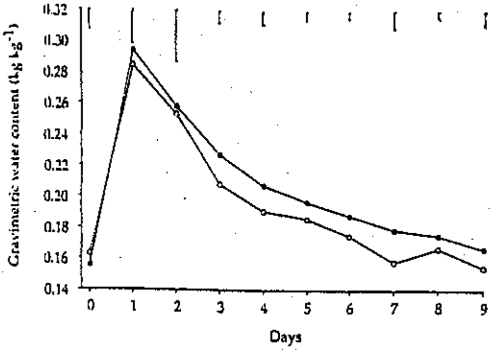

Fig. 3. Gravimetric water content of soil (46-90 mm depth) tilled to 0-45 mm (closed symbols) and tilled to 0-90 mm (open symbols) at each of days 0-9 (error bars; l.s.d., n=20, P<0.05)

was low in both treatments with only 51% emerged in the treatment tilled 0-90 mm and 36% emergence in the treatment tilled 0-45 mm (Table 1; Fig. 4). At day 3, the total length of roots in the treatment tilled 0-90 mm was 36 mm whereas in the treatment tilled 0-45 mm it was 20 mm (l.s.d.=5, P<0.05). Roots of seedlings in the treatment tilled 0-90 mm were not waterlogged because they did not reach the free water which at days 0-1 was perched on the untilled soil below (i.e. 80-90 mm depth).

TABLE 1 Effect of tillage depth on the fate of seedlings at day 10

Tillage depth (mm)	Seedling fate (%) Emerged	Unemerged	Obstructed
0-45	36 ± 2[a]	5 ± 1	47 ± 3
0-90	51 ± 2	1 ± 1	39 ± 1

[a]Predicted mean ± standard error of the mean

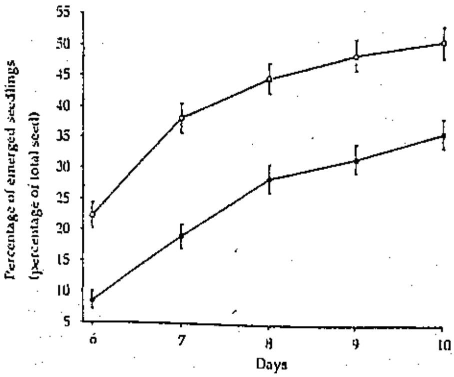

Fig. 4. Percentage of seedlings to emerge in soil tilled to 0-45 mm (closed symbols) and 0-90 mm (open symbols) at days 6-10 (error bars; predicted standard error of mean)

DISCUSSION

Our results show that the elongation of coleoptiles was the main limitation to the emergence of wheat seedlings (Table 1), since germination was high in both treatments. For example, at day 10, 90% of seeds had germinated and no treatment had more than 51% emergence (Table 1; Fig. 4). Most of the unemerged coleoptiles were physically obstructed (Table 1) by hard soil (Fig. 2) and most of those were buckled especially when they had unfurled into leaves.

Coleoptiles which emerged on day 7 in the treatment tilled 0-45 mm penetrated a crust with a penetrometer resistance of 1.1 MPa (Fig. 2) which Hadas and Stibbe (12) calculated to be soft enough (<1.5 MPa) not to restrict emergence of wheat seedlings. On the other hand, in the treatment tilled 0-90 mm, coleoptiles emerged through a crust of 1.7 MPa (Fig. 2), 21% harder than the limit calculated by Hadas and Stibbe (12) from measurements with a pocket penetrometer (shape, speed and thickness of needle not quoted). Between days 7-10 in both treatments, a further 18% of coleoptiles emerged (Fig. 4), in spite of the soil 0-45 mm depth drying by 0.1 kg kg^{-1} (Fig. 3), and probably becoming harder (9) than that measured at day 7.

The more favourable physical properties of the soil 46-90 mm depth on the roots account for the higher percentage of coleoptiles to emerge (Fig. 4) through harder soil 0-20 mm depth in the treatment tilled 0-90 mm than that tilled 0-45 mm (Fig. 1, Fig. 2). At day 3, the untilled soil 46-90 mm depth restricted the total length of roots to 44% of those in the treatment tilled 0-90 mm. Roots in the treatment tilled 0-45 mm were temporarily waterlogged, whereas roots in the tilled soil were aerobic. Anaerobic soil decreases the length of roots because it impairs the uptake of water and of nutrients or it produces phytotoxic substances (13). The roots restricted by waterlogged soil decreased the elongation of coleoptiles in a similar manner to that described by Trought and Drew (14) where roots in waterlogged soil decreased the rate of elongation of leaves during post-emergence. In addition, the length of roots may have also been restricted by the harder untilled soil compared with the softer tilled soil (e.g. 46-90 mm depth) (Fig. 1, Fig. 2) since the length of roots is usually negatively correlated with penetrometer resistance (15). The roots grown in the hard untilled soil may have decreased the rate of elongation of coleoptiles in a similar manner to that described by Malse and Passioura (11). They proposed that roots in hard soil produced hormones that caused the elongation of leaves to decrease as early as two days after the crop had emerged. Our results suggest that this response begins before coleoptiles emerge.

The slower rate of elongation of coleoptiles does not account entirely for the fewer coleoptiles to emerge during the experiment in the treatment tilled 0-45 mm compared with treatment tilled 0-90 mm (Fig. 4). At days 3-9 the soil 46-90 mm depth was 6-9% wetter (but not waterlogged) in the treatment tilled 0-90 mm than in the treatment tilled 0-45 mm (Fig. 3). We speculate that in the treatment tilled 0-90 mm, more water was available to the roots causing the coleoptile to develop greater tugor pressure and thus greater force on the soil than in the treatment tilled 0-45 mm (12). Waterlogged soil which decreases the uptake of water by the roots (13) could have also decreased the pressure of the coleoptile on the soil in the same manner to that just described.

CONCLUSIONS

Germination was not greatly affected by tillage below the seed because the soil was moist when the seeds were germinating, but several other physical properties of the soil restricted emergence. Emergence decreased when roots were grown in untilled soil, because they were restricted by hard, waterlogged and/or dry soil compared with the tilled soil.

We found that emergence was riskier when the direct-drill placed seeds onto untilled soil compared with tilled soil. A system of direct-drilling which increases the drainage and storage of water and which loosens the soil immediately below the seed would increase emergence on hardsetting soils.

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EFFECTS OF SOIL COMPACTION ON THE GROWTH AND NUTRIENT UPTAKE OF BARLEY AND MAIZE

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ABSTRACT

A field experiment was carried out to evaluate the effects of various soil compaction levels on root growth and nutrient concentration of spring barley and maize. Increasing soil compaction resulted in a greater surface root concentration. The effect of soil compaction on nutrient uptake was related to plant growth phase, compaction level and precipitation. At maturity, reduction in concentration of nitrogen, phosphorus and potassium occurred mostly at high compaction levels. The reductions were relatively greater for P than N and K. In wetter season the concentration of nitrogen and potassium in maize increased with soil compaction and that of P decreased. The nutrient concentrations in grains were less affected than in shoots.

INTRODUCTION

Soil compaction influences several aspects of soil environment such as strength, air, water, heat and biological activity which in turn affect root growth and uptake of mineral elements (9,11). A common response of root systems to increasing level of soil compactness is a decreased root size, retarded root penetration and smaller rooting depth (3,4,5) and increasing irregularity of root arrangement resulting in greater distances for the transport of water and mineral elements to the nearest root (10).

Some laboratory studies have indicated that in a certain range of moderate compaction soil can be more effective medium for transmission and uptake of water and mineral elements owing to increased hydraulic conductivity (8), higher diffusion coefficients of ions (2) and higher root-soil contact area. This may partly compensate reduced uptake resulting from restricted root growth in compacted soil.

In field conditions the compensatory effect is largely dependent on the level of soil compactness, root arrangement and nutrient and water supply. This paper examines the effects of various levels of soil compactness on growth and nutrient concentration of spring barley (Hordeum vulgare) and maize (Zea mays) grown in the field.

MATERIALS AND METHODS

Field experiments were carried out on an Orthic Luvisol developed from silt formations in the Lublin region, Poland. The soil contained 26% sand, 65 % silt and 9 % clay in the topsoil. Traffic of various intensity was applied uniformly by successive side by side passes of a tractor before sowing. An approximately uniform seedbed for all treatments was prepared. Soil compactness was expressed in terms of the "degree of compactness", being a percentage of a reference bulk density for the same soil (6). Spring barley and maize were grown in different years.

Penetration resistance was measured in the field at soil water content near "field capacity" with a cone angle of 30° and an area of 1 cm^2 shortly after emergence. Root length (10 replications) was determined by the Delta-T root length measurement system at anthesis.

N concentration was determined with method of Kjeldahl and other nutrients by analyzing proper extracts of the ash by Atomic Absorption Spectrophotometry Perkin Elmer 330. The results are given in % of dry matter.

RESULTS

Precipitation during growing season of barley (May-July) was 139 mm which is 67 % of the long term average precipitation. For the full growing season of maize (May-October) the precipitations reached 291 mm and 190 mm for the period from sowing to anthesis (May-July). They consist 78 % and 92 % of the long term average, respectively.

Differences in cone resistance between the treatments were large (Fig. 1). Maximum resistance values within the plough layer increased with soil compaction from 0.38 MPa for a degree of compactness of 74 % to 2.3 MPa for a degree of compactness of 98 %.

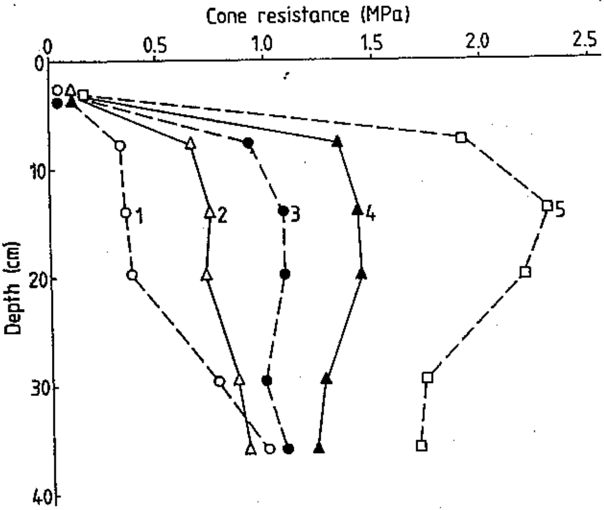

Fig. 1. Cone resistance at soil water content near "field capacity" for various degrees of compactness: 74 %(1), 85 %(2), 89 %(3), 92 %(4) and 98 %(5).

Different levels of soil compaction had significant effects on the distribution of root length density (Fig. 2). Increasing soil compactness resulted in a greater concentration of roots in the surface soil and decreased rooting depth. This effect was more pronounced with barley grown in drier season. In early study it was shown that higher surface concentration of barley roots in compacted soil was due to more horizontal growth (7). Thickening and flattening of the roots and distorted epidermal cells implied that the main factor limiting the root growth was soil strength.

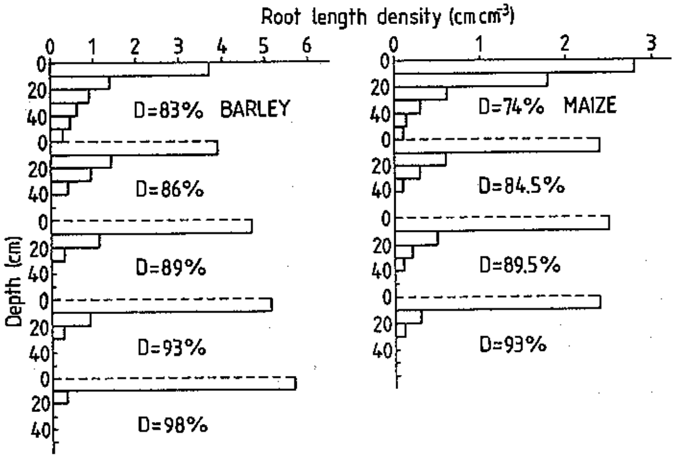

Fig. 2. Root length density distribution in relation to the degree of compactness.

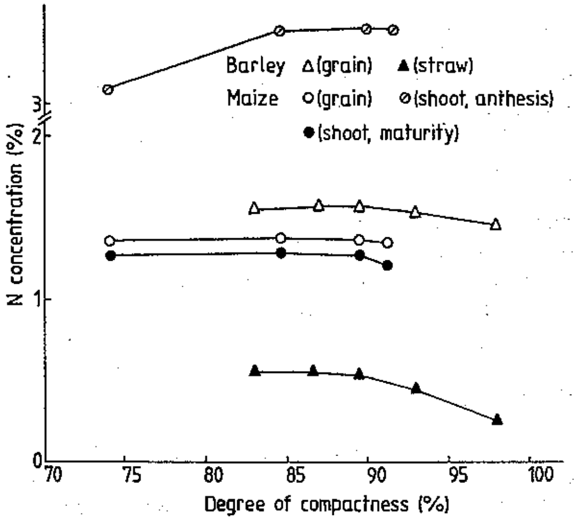

Fig. 3. N concentration in relation to the degree of compactness.

The effect of soil compaction on nutrient concentration is considerably affected by crop type and plant growth phase and the nature and mobility of individual ions. Within the range of lower degree of compactness nitrogen concentration of barley and maize at maturity was slightly affected and decreased when the degree of compactness exceeded value 88 % (Fig. 3). However, at anthesis the nitrogen concentration in shoot of maize increased with the soil compaction increase.

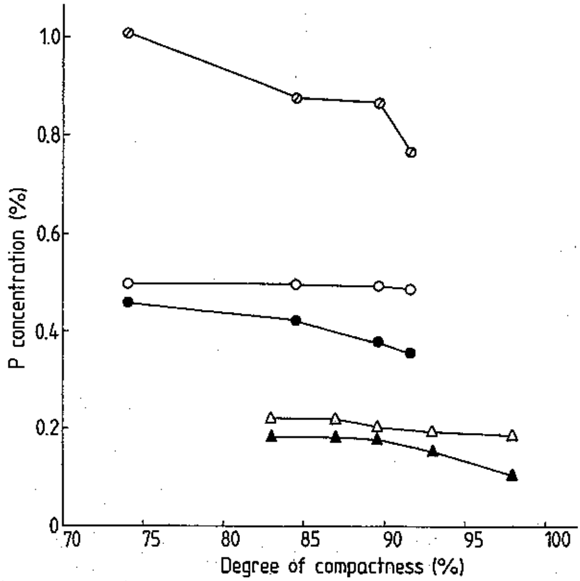

Fig. 4. P concentration in relation to the degree of compactness. Symbols used as in Fig. 3

Phosphorus concentration generally decreased with the degree of compactness (Fig. 4). The reduction was greater in shoot of maize and straw of barley than in grain of both crops. Irrespective of the soil compaction level the P concentration was considerably higher in maize than barley.

Figure 5 shows that potassium concentration of maize shoots at anthesis increased with soil compaction while that at maturity was almost not affected. The K concentration in barley straw decreased when the degree of compactness exceeded approximately 90 %. The P concentration in grains was highest at medium level of soil compaction.

Total amounts of all nutrients taken up are dependent on crop yield. The crop yield sharply decreased when the degree of compactness exceeded value of 88-91 % (7).

Comparison of the concentration of the particular nutrients at maturity indicates that P concentration was more reduced by soil compaction than the concentration of N and K. This can be due to decreasing P availability resulting from both the restricted root system and low mobility of the nutrient. The increase in nitrogen and potassium concentrations with soil compaction was only observed in maize shoots at anthesis. This response can be attributed to relatively greater precipitation in the period from sowing to anthesis and greater influx per unit root surface in compacted soil. The differences in nutrient concentration of maize between the soil compaction treatments were lower at harvest than anthesis. The results are in agreement with findings obtained by Arvidsson (1).

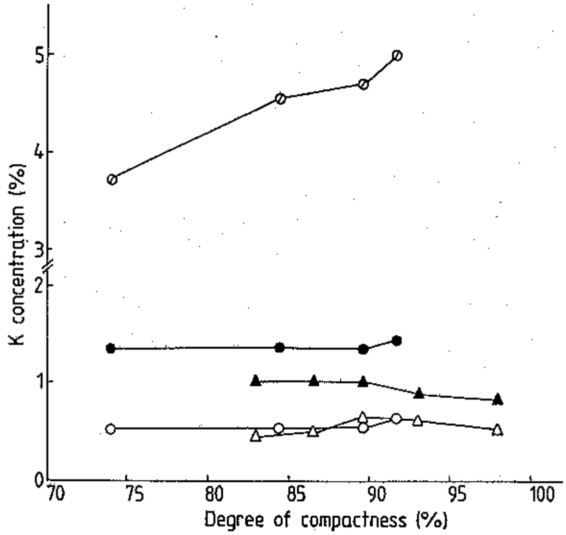

Fig. 5. K concentration in relation to the degree of compactness. Symbols used as in Fig.3.

The concentration of some nutrients nutrients in roots of spring barley as related to soil compaction is reported in Table 1. Reduction in concentration of P and Ca with increasing soil compactness was observed. The concentration of K was highest at medium level of the degree of soil compactness.

TABLE 1 Nutrient concentration as related to the degree of compactness.

Degree of compactness (%)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
83.0	0.60	0.21	0.18	0.19	0.060
86.5	0.60	0.21	0.28	0.16	0.066
89.5	0.58	0.20	0.27	0.13	0.054
93.0	0.57	0.17	0.18	0.14	0.060
98.0	0.59	0.17	0.20	0.11	0.062

CONCLUSION

Effects of soil compaction on nutrient concentration in plants depends on the level of soil compaction, plant growth phase and precipitation. The reduction in concentration of N, P and K at maturity mostly occurred at higher soil compaction range and was more pronounced in shoot than grain. The P concentration was more reduced than N and K. At anthesis, greater N and K concentration of maize grown in compacted soil was found.

ACKNOWLEDGEMENT

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ACTIVATION OF FIELD CROPS ROOT GROWTH UNDER UNFAVOURABLE SOIL-PHYSICAL CONDITIONS

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ABSTRACT

Agrochemical and agrotechnical methods activating roots growth and rising productivity field crops under unfavourable soil-physical conditions are considered. Application of inorganic fertilizers in compacted soil layers and of physiologically active substances and gypsum reduces the negative effect of overcompaction and moisture deficit on the yield.

INTRODUCTION

The soils overcompaction is observed under effect of farming intensification. Thus, the cultivated layer of the left-bank forest-steppe Ukrainian chernozems may be compacted to 1.35-1.40 g/cm^3. It is the upper limit of the optimum density for cereal roots, and the critical - for corn and row crops [1]. The high bulk density is a sufficiently high obstacle for the roots growth into the depth of soil profile. In this the roots growth rate reduces by several times [2], which is extremely unfavourable under conditions moisture deficit. Decrease in the root system vigor on overcompacted soils is accompanied by the productivity decrease of field crops and their ecological stability [3].

Attempts to find means for roots growth intensification in lower dense soil layers are known from the literature [4,5,6]. Nutritive elements and other substances have been used as growth stimulators for root systems. However such investigations are few and, the main thing, there is lack of reliable technical means for fertilizers application into dense soil layers. Methods for improving of root systems adaptation to compacted soils and moisture deficit by growth stimulators and calcium containing substances also almost were not tested. These points became the essence of our investigations.

MATERIALS AND METHODS

The investigations have been carried out on the chernozem typical heavy-loamy of the Ukrainian eastern forest-steppe (1983-1992). In vegetation-laboratorium and field experiments methods of mathematics planning with the application of fractional factor plans have been used. Factors on schemes presented in tables 1 and 2 have been studied in model field experiments for the activation of barley roots growth.

Table 1. Scheme of the 3-factors experiment

Factors	Level of validation		
	0	1	2
X_1 - soil bulk density in the layer 10-30 cm, g.cm^3	0.9-1.0	1.1-1.2	1.3-1.4
X_2 - nitrogen,kg of active substance /ha	0	90	180
X_3 - depth of nitrogen application, cm	0-10	10-20	20-30

The experiment included 15 variants, replication - three fold.

Table 2. Scheme of the 5-factors experiment

Factors	Level of validation		
	0	1	2
X_1 - nitrogen,kg of active substance/ha	0	45	90
X_2 - phosphorous,kg of active substance/ha	0	45	90
X_3 - potassium,kg active of substance/ha	0	45	90
X_4 - soil bulk density in the soil layer 10-30 cm,g/cm^3	0.9-1.0	1.1-1.2	1.3-1.4
X_5 - depth of N, P and K application, cm	0-10	10-20	20-30

The number of variants in the experiment - 26, replication - quadruple.

The growth stimulators are tested in vegetation and laboratorium experiments according to schemes presented in tables 3 and 4.

Table 3. Scheme of the 3-factors experiment

Factors	Level of validation		
	0	1	2
X_1 - soil bulk density,g/cm^3	0.9	1.15	1.40
X_2 - soil moisture, fraction of the Field Capacity (FC)	0.6	0.8	1.0
X_3 - soidium humate mg/kg soil	0	12	24

The number of variants - 15, replication - quadruple, crop-barley.

Table 4. Scheme of the 4-factors experiment

Factors	Level of validation		
	0	1	2
X_1 - soil moisture, fraction of FC	0.6	0.8	1.0
X_2 - phosphorous,kg of active substance/ha	0	90	180
X_3 - gypsum, g/kg soil	0	1	2
X_4 - heteroauxin, mg/kg soil	0	0.1	0.2

The number of variants -24, 4 replications, crop-barley.

Separate methods of the root growth activation have been tested in many years production corn souwings in variants: 1 - control without fertilizers, 2 - application of liquid complex fertilizers (LCF) into the layer 0-7 cm (a standard method), 3 - application of LCF in the soil layer 25-30 cm. Fertilizers have been applied by implement especially manufactured according to our agrodemands. The instrument for the liquid mineral fertilizers application into the soil is the plain horizontal knife of the curvilinear shape with the minimum cross-section square. Such working organ allows to apply fertilizers on the depth up to 30 cm and provides creation of the subseed layers bulk density in the interval 1.1-1.2 d/cm^3.
We separated the root system from the soil according to developed by us method [7].
Effect of factors we evaluated on following criteria: mass, roots morphology and productivity, root penetration of soil layers and crop yield.

RESULTS AND DISCUSSION

Research during field trials have shown that fertilizers application in a dense layer brings to the significant increase of the roots mass in the lower part of cultivated layer.
However the efficiency of separate parts of the mineral nutrition was various and depended from meteorological conditions. Experiment results under normal hydrothermic conditions evidence that nitrogen applied into compacted part of cultivated layer favours the uniform occupying of soil profile by barley roots. It is characteristically that the roots growth in compacted horizons intencifies and their mass increases by 1.5-3 times [table 5]. The data show that compacting of the cultivated layer lower part to 1.3-1.4 g/cm^3 results in the horizontal roots growth, main part of which is concentrated in the 0-10 cm layer (82.9-87.2% of the roots mass in the cultivated layer).
The standard method of nitrogen application into soil increases the surface roots distribution not only in the soil with the differentiated cultivated layer, but also at its homogene configuration. The barley root mass in the upper layer increases by 10.7% in comparison with variants, where fertilizers were applied into the 20-30 cm layer. The even roots growth leads to the increase of their productivity. The productivity coefficient [8], as a generalized index of the main functions of the plant underground part increases at the nitrogen application into the cultivated layer lower part.

Table 5. Growth and productivity of barley roots depending on the depth of nitrogen fertilizers application.

Variant: Bulk density g/cm3	Variant: Depth of nitrogen application cm	Roots mass in cultivated layer, t/ha	Roots distribution, %, in soil layers, cm: 0-10	10-20	20-30	Productivity coefficient	Grain mass t/ha
0.9-1.0	Not applied	8.6	68.9	21.9	9.3	0.41	3.5
	0-10	8.3	80.0	10.7	9.3	0.40	3.4
	20-30	8.6	69.0	14.7	17.0	0.45	3.8
1.3-1.4	Not applied	6.1	89.2	11.9	5.2	0.71	4.2
	0-10	6.0	87.2	9.7	3.7	0.71	4.2
	20-30	6.1	70.4	14.5	15.1	0.82	5.0

At the same time improvement of roots morphological parameters was observed: their deformation and thread-likeness were removed, the mass of roots active fractions increased. As a result reliable barley yield increases have been obtained.

Under unfavourable weather conditions (for example,during one of vegetation periods precipitations were 148 mm with their mean many years level of 331 mm) nitrogen fertilizers exerted a negative effect on the roots growth, their productivity and barley yield. The worst was the plant reaction on nitrogen application into the surface soil layer. Potassium exerted no reliable effect on roots growth, but at the common application with nitrogen it aggregated the negative effect of the latter. Under such unfavourable conditions the most effectivity exerts phosphoruos. The total roots mass in the cultivated layer at its application on variant with the increased bulk density increased from 1.2 to 1.7 t/ha (Table 6)

Table 6. Barley roots growth and productivity depending on the depth of phosphorous fertilisers application

Variant: Bulk density g/cm3	Variant: Depth of phosphorous application cm	Roots mass in cultivated layer, t/ha	Roots distribution, %, in soil layers, cm: 0-10	10-20	20-30	Productivity coefficient	Grain mass, t/ha
0.9-1.0	Not applied	2.3	60.1	20.1	19.9	0.40	1.1
	0-10	1.9	72.1	19.7	14.2	1.16	2.2
	20-30	2.0	45.7	26.6	27.8	1.30	2.6
1.3-1.4	Not applied	1.2	56.4	31.7	12.3	1.33	1.6
	0-10	1.8	56.9	35.2	7.9	1.61	2.9
	20-30	1.7	44.7	28.6	26.7	2.06	3.5

Effectiveness of deep local application of inorganic fertilizers was tested in the production (Table 7). Obtained results evidence that application of LCF in the soil layer of 25-30 cm compacted to that application of (plow sole) favours the even roots growth in the soil profile of 0-60 cm. 1.5-2 times more roots penetrated subsoil than at a standard method, roots productivity and corn for silage yield increased .

Table 7. Corn yielding capacity depending on method of inorganic fertilizers application, t/ga

Depth of fertilizers application, cm	Investigation years				
	1986	1987	1988	1989	1990
Control (withount fertilizers)	21.1	38.1	53.6	32.0	-
0-7	22.0	40.2	52.0	57.0	46.0
25-30	24.0	53.2	59.0	68.0	56.6
LSD 0.5	2.6	3.8	2.7	2.5	2.9

The positive gypsum effect (1-2g/kg soil) on barley roots growth in a dense soil has been established in the vegetation experiment. We should mention that this soil has been compacted to a critical level for oats development (1.35-1.45g/cm^3) soil. The roots growth increased at gypsum aplication: under moisteming it increased by times in comparison with the control variant. Heteroauxin also exerted a stimulating effect on roots growth and productivity in our experiments. Its maximum efficiency was noted at the rate of 0,1 mg/kg soil. The use of heteroauxin permitted, due to increase in roots growth and productivity, the oats grain mass gain by 120 and 80% at soil moisture accordingly 0.6 and 1.0 of the FC. Heteroauxim by it's common application with phosphorus or gypsum increases their positive effect on the oats roots growth activation and yield: at the moisture deficit efficiency of phosphorus increases almost by 3 times, of gypsum - by 1.5-2 times.

There have been tested humine fertilizers for roots growth activation under unfavourable conditions. Sodium humate exerted (12-24 mg/kg soil) the positive effect on roots growth, their productivity and yield of the above ground mass under extreme conditions of soil moisture and density.

Efficiency of humic fertilizer is higher at the bulk density deviating from the normal one. Sodium humate exerts the most effect at conditions of moisture deficit. Under combination of unfavourable factor in the experiment - excessive loose soil and moisture deficit, compacted soil and moisture deficit - there is observed the rise in roots productivity in the former case - by 2.5 times, in the latter case - by 1.5 times in comparison with varionts without humate application. Obviously, sodium humate activates the roots main phisiologycal functions (intake and synthesis). The yield in experimental variants distinguishes by two times at the same mineral nutrition.

CONCLUSION

The intrasoil application of nitrogen and phosphorus at the depth of the compacted interlayer of special tool is effective at field crops cultivation on overcompacted chernozems. This method activates root growth in layers, promotes the even root penetreability of soil profile, effective use of soil storage on moisture and nutritive substances, grain yeild increase of cereal crops by 0.6-0.7 t/ha, crop green mass - by 10.5-11 t/ha in comparison with the standard method of fertilizers application.

Under application of physiologically active substances and gypsum the negative effect of soil compactness on growth and productivity of field crops roots lower. Sodium humate (12-24 mg/kg soil) and heteroauxim (0.1mg/kg soil) improve the roots growth, active their physiological activity. The maximum effeciency of growth stimulators in noted at the moisture content of typical chernozem in the interval of 0.6-0.7 of FC.

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COMPACTION OF A SANDY SOIL AS RELATED TO ROOT SYSTEM AND AERIAL PARTS DEVELOPMENT AND YIELDS OF SPRING BARLEY

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ABSTRACT

The paper examines the development of roots and aerial parts and the yields of spring barley as influenced by different degrees of soil compaction produced by an impact of tractor wheels passing once or more times over the field.

INTRODUCTION

Soil degradation brought on by an increasing use of agricultural machinery is a problem of concern for both agronomists and environmentalists.

Extent of resistance offered by the soil to root penetration is of critical importance for the rooting process. Penetration resistance is expressed in terms of volumetric weight and compaction units.

Soil compaction is an important factor that shapes soil environment during plant germination and emergence (3). The effects produced over a wide range of compaction degrees are reflected by crop yields (2, 3, 4, 5, 6).

MATERIAL AND METHODS

The field experiment was run over the years 1991-1993 on a sandy soil. The design was strip trial with four replications. Five different degrees of soil compaction were the result of the following tillage treatments:

I - control - conventional tillage and husbandry practices standard in barley production; plus a series of tractor wheel passes over the same track:
II - single
III - twofold
IV - threefold
V - fourfold

At the time the impact of tractor wheels was applied the sandy soil had a gravimetric moisture content of 10.6%. The measurements of soil density and penetration resistance were made at the time of spring barley emergence. The soil was sampled for volumetric density measurements at 2-7, 17-22, 32-37 and 47-52 cm depths using Kopecki cylinders. Penetration resistance was determined in the 0-50 cm soil layer using Eijkelkamp penetrograph.

RESULTS AND DISCUSSION

Changes in the density of the sandy soil produced by the impact of tractor wheels are presented in Table 1.

Table 1 Effect of compaction treatments on soil bulk density ($Mg.m^{-3}$). Values averaged over three years

Compaction treatments	Depth (cm)			
	2-7	17-22	32-37	47-52
I	1.46	1.56	1.69	1.69
II	1.55	1.60	1.73	1.70
III	1.56	1.61	1.74	1.71
IV	1.56	1.61	1.75	1.76
V	1.58	1.65	1.73	1.76
LSD (.95)	0.110	0.050	0.060	0.080

The density values varied from 1.46 to 1.76 $Mg{\cdot}m^{-3}$ over the three-year study period . The closest relationship between the density of the sandy and the number of tractor wheel passes was found in the surface layer (2-7 cm.) The wheel impact-dependent variation in soil density declined with the depth of soil profile. The analysis of variance showed that the density of the soil was significantly dependent on the wheel impact treatment.

The earlier investigations by the authors of this presentation (1), carried out on three soils belonging to the alluvial, loess and sandy groups, also demonstrated a significant rise in soil density produced by the impact of tractor wheels.

Variation in soil density subject to varying number of passes by tractor wheels is shown in Table 2.

Table 2 Effect of compaction treatments on soil penetration resistance (MPa). Values averaged over three years

Compaction treatments	Depth (cm)			
	5	20	35	50
I	0.1	1.0	4.0	4.5
II	0.4	2.7	4.2	4.6
III	1.0	3.5	4.4	4.8
IV	1.5	4.3	4.5	4.7
V	1.9	4.3	4.6	4.8

The soil density values ranged from 0.1 to 4.8 MPa. Soil density rose with the number of wheel passes and with the depth of soil profile. There was a positive relationship between the wheel impact-related rise in soil density and its penetration resistance. The relationship was closest in the surface soil layer (0-20 cm) and was detectable as far downprofile as 35 cm.

The data on the response of spring barley to the wheel impact-related changes in sandy soil density are shown in Table 3.

Table 3 Effect of compaction treatments on the performance of spring barley grown on a sandy soil
Not significant: n.s.

Year	Compaction treatment	Seeding depth (cm)	Number of plants per 1 m after emergence	Number of plants per 1 m before harvest	Grain yield ($t \cdot ha^{-1}$)	Straw yield ($t \cdot ha^{-1}$)
1991	I	3.9	36	20	4.77	3.98
	II	2.8	35	20	4.72	3.90
	III	2.3	35	20	4.48	3.58
	IV	2.2	32	19	4.45	3.52
	V	1.7	30	19	4.30	3.27
	LSD (.95)	1.11	5.5	n.s.	0.502	0.405
1992	I	2.6	40	36	3.25	2.48
	II	2.3	38	32	3.15	2.35
	III	2.0	36	32	3.07	2.27
	IV	1.6	36	32	2.91	2.09
	V	1.4	30	28	2.71	1.94
	LSD (.95)	0.26	7.5	5.9	0.288	0.226
1993	I	2.6	30	20	2.70	1.79
	II	2.4	28	21	2.24	1.77
	III	2.0	25	21	2.15	1.77
	IV	1.9	24	22	2.04	1.65
	V	1.6	22	22	1.82	1.52
	LSD (.95)	0.39	6.6	n.s.	0.394	n.s.

The analysis of variance showed that over the three-year study period the wheel impact treatments significantly influenced seeding depth, post-emergence number of plants per 1 m, and grain yields.

As the studied soil became more compacted there was a progressive decrease in seeding depth, number of plants per 1 m and a reduction in the yield of grain and straw of spring barley. The repeated impact of tractor wheels caused grain yields to decrease by 1-10%, 3-17%, and 17-33% on the uncompacted control in 1991, 1992 and 1993, respectively.

Such a substantial decline in spring barley yields in 1993 was caused by long spell of drought in the spring which further aggravated the adverse effects of excessive soil compaction.

The authors found a similar phenomenon in their earlier study (1) conducted in the years 1987 - 1990. Under equally adverse weather conditions the reduction of barley grain yields on the sandy soil compacted with three consecutive passes of a tractor was 25% on the check uncompacted treatment.

The effect of compacting the sandy soil on the development of barley root system is shown in Table 4.

Table 4 Effect of compaction treatments on barley root development -- root weight values at anthesis (g dry matter in 630 cm^3 soil)

Compaction treatments	depth (cm)				
	0-12.5	12.5-25	25-37.5	37.5-50	Σ 0-50
I	0.66	0.18	0.16	0.16	1.16
II	0.69	0.16	0.09	0.09	1.03
III	0.71	0.20	0.09	0.03	1.03
IV	0.47	0.13	0.05	0.05	0.70
V	0.39	0.11	0.06	0.03	0.59

The most severe check of root growth was found following three and four passes of the tractor. The reduction of root weight in the 0-50 cm layer was 40 and 50% on the uncompacted control treatment, respectively. One and two passes of the tractor brought about a 10% decline in root weight relative to the control.

CONCLUSION

Soil compaction brought about by repeated passing of tractor wheels results in the rise of density and resistance to penetration of a sandy soil. Those changes in the soil significantly restrict seeding depth, number of plants per 1 m, root growth, and yields of grain and straw of spring barley. As the number of tractor passes increases from 1 to 4 the weight of roots decreases by 10-50% in the 0-50 cm soil layer and grain yields decline by 10-33% on the uncompacted control.

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INFLUENCE OF TILLAGE AND FERTILIZING ON ROOT DEVELOPMENT AND YIELD OF VIRGINIA TOBACCO IN NORTHERN CROATIA

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ABSTRACT

Effects were studied of the ploughing depth (20, 30 and 40 cm), method of tobacco planting (without ridges, autumn ridges and spring ridges) and fertilizing (0-50-150, 20-50-150 and 40-50-150 kg NPK/ha) upon soil compaction, root development and yields of Virginia tobacco. Investigations were set up on luvisol in northern Croatia and continued for three years. The highest compaction was recorded on the soil to which shallow ploughing was applied. A significantly higher root mass and a higher yield of tobacco leaves were achieved in the treatment involving a ploughing depth of 40 cm and fertilizing with 40 kg N, 50 kg P_2O_5 and 150 kg K_2O.

INTRODUCTION

Virginia tobacco is the main component of American blend cigarettes.This tobacco, introduced into Croatia in the 1950s for the needs of tobacco industry,is grown on sandy soils in northern Croatia, which are favourable for its production (1,2,3,4), Economic effects and the farm size were the principal reason for tobacco being frequently grown in monoculture. Frequent shallow tillage to the same depth led to intensified compaction of the subsoil layer (5, 6, 7,8). High compaction of the topsoil and subsoil obstructs the growth and development of roots. Such soil copaction also imposes limits on tobacco yields, in some cases even more so than nutrient deficiency (9).
The object of this work was to resolve a part of this complex problem, with the emphasis on achievement of cost efficient yields of good quality tobacco.

MATERIALS AND METHODS

Investigations continued for three years (1983-1985). Influence of the ploughing depth, row ridge preparation and fertilization on the tobacco yield was studied.

Table 1 Trial treatments

Ploughing depth	Row ridge preparation	Fertilizing N, P, K/ha
20 cm	Without ridges	0-50-150
30 cm	Autumn ridges	20-50-150
40 cm	Spring ridges	40-50-150

The size of the basic plot was 57.6 m² (12 x 4.8 m). Four rows of tobacco were planted per plot. Fertilizing involved application of single fertilizers (calcium ammonium nitrate, triplex and potassium sulphate). Phosphorus and potassium rates applied in the trial were constant and amounted to 50 kg P_2O_5 and 150 kg K_2O per hectare. Nitrogen was applied at 20 and 40 kg rates. Two middle rows of each experimental plot were harvested for yield assessment.During the tobacco flowering period, soil resistance to penetration was measured every 10 cm at all ploughing depths. At the end of the growing season, tobacco roots were taken out by the monolith method and the main root mass was determined by sieving (10).

RESULTS AND DISCUSSION

The soil

The soil under study is sandy loam.It is porous in the topsoil horizon while slightly porous and compacted in the eluvial and illuvial horizons, which hinders penetration and root development (Table 2). Air capacity is particularly low in the eluvial horizon.

Table 2 Physical properties of the soil

Horizon	Depth	Total porosity	Water capacity	Air capacity	Bulk density
	cm	%	%	%	gr/cm³
A_p	0-24	45.6	36.4	9.2	1.46
E	24-41	38.3	33.7	4.6	1.68
B_t	41-78	41.6	34.1	7.5	1.71

The soil is acid, poorly humous, poor in total and mineral nitrogen,with an average content of available phosphorus and potassium (Table 3).
According to the listed physical and chemical properties,this soil is typical of the virginia tobacco growing region in Croatia.

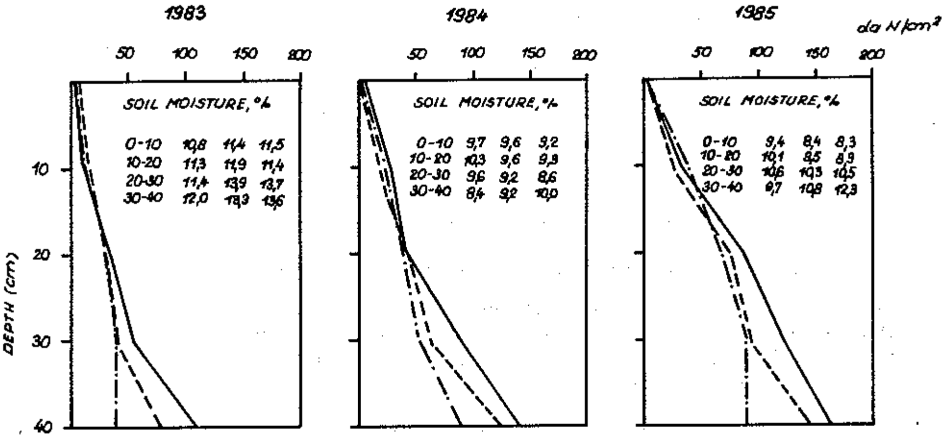
Table 3 Chemical properties of the soil

Horizon	pH		Humus	Total	Available	
	H_2O	n KCl	%	nitrogen	P_2O_5	K_2O
					mg/100 g soil	
A_p	4.9	4.0	1.31	0.05	14.9	20.3
E	5.6	4.6	0.28	0.04	12.8	16.7
B_t	5.9	4.8	0.35	0.02	7.8	7.1

Soil resistance

Soil resistance to penetration was measured with a penetrometer down to a depth of 40 cm and soil samples were taken for moisture determination. A significant influence of the ploughing depth on soil compaction was established in all three investigation years (Figure 1).

Figure 1 Effect of the ploughing depth on soil résistance



———— ploughing to 20 cm
- - - - - ploughing to 30 cm
— · — · — ploughing to 40 cm

Significant differences in soil resistance were recorded at depths that were not ploughed. The highest soil resistance was recorded at a measurement depth of 30-40 cm in the trial variant with shallow ploughing (at 20-30 and 30-40 cm) as well as in the variant ploughed at 30 cm, which seams logical since these layers were not ploughed and, thus, there were no mechanical practices to loosen the naturally compacted soil profile (11,12,13,14). Shallow ploughing demonstrated a significantly higher resistance in the subsoil in comparison with medium deep and deep ploughing. This resulted in poorer development and a lower yield of tobacco leaves.

Influence of soil tillage on the development of tobacco roots

The commonly practised shallow tillage for tobacco on the investigated soil often reduces the yields because, due to its unfavourable physical properties, there are no normal conditions for root development.
In all three investigation years, increases of the ploughing depth were followed by significant increases in the measured root mass (Table 4).
By increasing the basic soil tillage from 20 to, respectively, 30 and 40 cm, the development of tobacco roots was increased by 13.3 and 29.3 %, respectively, in three years. Almost identical results were also obtained for tobacco leaf yields, which points to strong correlations between these two parameters.

Table 4 Influence of the ploughing depth on the growth and development of tobacco roots, expressed in relative %

Ploughing depth cm	Year			Average
	1983	1984	1985	
20	100	100	100	100
30	118.9	109.2	111.7	113.3
40	136.8	126.6	124.6	129.3
LSD 5%	26.9	15.6	8.5	
1%	NS	21.3	NS	

Influence of soil tillage and fertilizing on the yield of tobacco leaves

Ploughing depth had a significant effect on the yield of tobacco leaves. The significantly lowest yield was recorded in tobacco grown on the soil ploughed at 20 cm, and the highest on the soil ploughed at a depth of 40 cm.Ploughing at 30 cm brought an average yield increase of 13.0 % and ploughing at 40 cm an increase of 17.1 % in comparison with the ploughing at 20 cm (Table 5), which points to a positive response of tobacco, in terms of root development and yield, to deeper ploughing.

Table 5 Effect of the ploughing depth on the yield of tobacco leaves, kg/ha

Ploughing depth cm	Year			Average
	1983	1984	1985	
20	2319.0	2304.8	2183.6	100
30	2609.4	2600.0	2485.6	113.0
40	2743.0	2632.8	2597.5	117.1
LSD 5%	171.9	155.9	291.2	
1%	258.9	291.2	NS	

Row ridge preparation for tobacco had a significant effect on the yield of tobacco leaves. Tobacco was planted on a flat surface and on ridges prepared in the autumn and spring. The lowest yield was recorded in tobacco planted on autumn ridges and the highest in tobacco planted on spring ridges (Table 6).
The third investigated factor was fertilization. Application of 20 and 40 kg of nitrogen resulted in yield increases in all three investigation years (Table 7).
In the three-year average, the application of 20 and 40 kg of nitrogen brought about yield increases of 8.7 and 14.8%, respectively,in comparison with the variants in which only phosphorus and potassium were applied. No interactional effect of tillage and fertilizing on tobacco yields was determined.

Table 6 Effect of row ridge preparation on the yield of tobacco leaves, kg/ha

Row ridge preparation	Year			Average
	1983	1984	1985	
Without ridges	2550.0	2430.1	2379.5	100
Autumn ridges	2468.1	2367.1	2350.0	95.9
Spring ridges	2655.4	2740.4	2487.2	100.7
LSD 5%	91.5	113.9	112.8	
1%	125.4	156.1	NS	

Table 7 Effect of fertilizing on the yield of tobacco leaves, kg/ha

Fertilizing kg/ha	Year			Average
	1983	1984	1985	
0-50-150	2346.0	2353.4	2234.4	100
20-50-150	2604.1	2497.6	2433.5	108.7
40-50-150	2723.4	2686.9	2548.8	114.8
LSD 5%	86.1	96.0	92.5	
1%	114.7	127,8	123.2	

CONCLUSIONS

1. A significantly lower compaction and better root development were recorded in the trial variant with the deepest ploughing.
2. The significantly highest tobacco yield was achieved in the variant in which tobacco was planted on spring ridges in the soil ploughed at 40cm and fertilized with 40 kg N, 50 kg P_2O_5 and 150 kg K_2O.

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ASSESSMENT OF WATER AVAILABILITY TO PLANTS

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ABSTRACT

The value of critical matric pressure (Pcr) is of great practical consequence for the estimation of water regime of plants,management practice for control of on-farm irrigation and development of water and matter transport models in soil and landscapes.It straightly depends on the logarithm of root concentration, but this dependence is different for plant species and hydrodynamics properties of soils. The integrated parameter for water management and productivity models on the basis of Pcr is proposed:the quantity of days when P<Pcr at the depth established.This parameter is in direct inverse connection with the crop of luzern.

INTRODUCTION

Mathematical models of water movement in soil-plant system are used in agricultural and management practice to maximize crop yields total net profit and to forecast the changes of natural hydrological,biological and soil conditions (1,4).All physically based mathematical models require the necessary experimental information concerning water availability to plants. Water consumption by plants depends on soil matric water potential (P) in a way of "transpiration trapezium":at given meteorological conditions, when P more than "critical" value (Pcr) the relative transpiration (T/To) is constant and maximal, and when P<Pcr, T/To and accordingly soil water availability decrease. The value of Pcr is the most important value for the estimation of water availability to plants. Now,we know, that Pcr changes with texture of soil, it increases with the meteorological stresses, it depends on kxerophytic state of plants (4,5). But, as a rule, the value of Pcr was investigated in special vegetational experiments, where the soil was homogeneous and distributions of soil moisture and plant roots were also uniform at the depth of soil. But in real conditions we have another picture:the distributions of P with soil depth are very contrast, especially in hydromorphic soils with shallow water table. The concentration of roots may also change Pcr,but the kind of this dependence is unknown.

Therefore, the aim of this paper is to present experimental dependencies, which are necessary for models of water movement in soil and plant productivity.Special tasks of the work are: (1) to take the function of Pcr from the root concentration and (2) to obtain the dependence of crop yield on water nutrition in terms of Pcr.

MATERIALS AND METHODS

The investigation the dependence Pcr on root concentration (C) was conducted in lysimeters and in field experiments.The surface of lysimeter was 500 cm^2 , depth - 100 cm.The lysimeters were filled by horizon A of 2 soils: chernozemic sandy and clay soil from the steppe zone.The water retention curves and unsaturated conductivity were estimated by membrane pressure apparatus with automatical control of soil moisture.

The lysimeter had a cut on one side, which was covered with plastmasse for investigating the growth of roots. The roots were drawn every day, the growth was determined, and in the end of the experiment the concentration of roots was investigated in every layer by the method of E.I.Newman (3).Comparing the data of roots concentration with their growth by drawings, the dynamics of roots concentration was calculated for each 10-cm soil layer. The soil moisture matric pressure was investigated by tensiometers at the depth of 20,40,60 cm.Moisture content was determined by neutrometer every day. Lysimeters were weighted every day, the accuracy of bulk water content determination was ±0.5%.The surface of soil in lysimeters was covered by the water impermeable film; so the transpiration (T) was estimated by the weight of the lysimeter. At the 1st stage of the experiment the plants (horse bean, oats) grew in optimal conditions: the plants were irrigated when the matric pressure achieved -20 kPa at the depth 20 cm. At the 2nd stage, the plants were divided into 2 groups: the 1st group was grown without atmospheric and irrigation water (soil drought), and the 2nd was in optimal soil-water conditions. The transpiration of the 2nd group plants was taken as a potential one (To).

In our field experiments for determining Pcr in different soil-hydrophysical conditions we used the dynamic data of P in soil profiles, T, To and biomass of plants and root concentration. These data were taken on meadow-chernozemic soils (Odessa region, Ukraine) with a water table at the depth of about 1.5 m. T was investigated by the method of rapid weighting , potential - by the same method on the plots where the matric potential was kept >-20 kPa at the depth of 20 cm by irrigation.The plants investigated were: the 3rd year luzern and maize.

RESULTS AND DISCUSSION

In the lysimeter and field experiments we determined Pcr, when T/To became below 1.We suppose that at that moment the water pressure distribution with the soil depth, which corresponds to the root distribution in profile is formed in soil. That is, we have Pcr in every soil layer whose magnitude depends only on root concentration (C). We assume that at the moment of decreasing T/To the water pressure in root becomes equal in the whole root system.So, at the moment of decreasing T/To, we determined C in different layers and P for these layers.

The dependence of Pcr on C (fig.1) is log-proportional.This means that for the concrete plant the optimal soil water diapason increases with the increase of the root concentration. We must emphasize that in these dependencies the role of plant physiology and hydrophysical properties of soil is shown very clearly. For example,compare the curves for horse beans and oats for the same soils, - the straight lines for oats on sandy and clay soils are higher than for horse beans. This means that plants of oats are more kxerophytic than those of horse beans.The analogous analysis may be done for other plants investigated.

The influence of soil properties on Pcr for a concrete plant may also be discussed. We can assume, that the direct proportional dependencies are acceptable for larger range of C. In that case for the equal C the plants on sandy soil have a lower Pcr for the range of P> -45 - -48 kPa (fig.1). But for P<-48 kPa the lower magnitudes of Pcr are characteristic for the clay soil.This magnitude , -48 kPa, is equal for oats and for beans, which testifies to its soil physical nature. We suppose that this value of P is in good agreement with P, when unsaturated conductivity of sandy soil becomes lower than that of the clay one.This fact shows the dominant role of soil water dynamic characteristics in plant-water relations. Such analysis, hypothetical as it is,nevertheless demonstrates the role of root concentration and soil hydrophysical factors for the models of water movement in soil with plant cover.

For the control on-farm water management we must utilize only one magnitude of P in the soil profile and this magnitude must be in the range of tensiometer.For automorphic conditions, when the distribution of P in the soil profile is uniform, many researchers have proposed the depth of 20-40 cm for investigating Pcr (2) But in the hydromorphic conditions with shallow water table, the distribution of P is not uniform: in the upper layers P<-70 kPa, but in the deeper ones 60-80 cm - P is about 1-10 kPa and changes only slightly.The investigations of P distribution and T/To allow us to establish the most useful magnitude of Pcr and the depth in soil with water table about 1.5-2 m: -30 kPa at the depth of 40 cm for maize, -50 - -55 kPa at the depth of 50 cm for the 2nd,3rd year luzern. These dependencies show that in hydromorphic conditions with shallow water table it is necessary to establish not only the magnitude of Pcr, but also the depth in soil where this Pcr must be controlled.

But in the management models it is necessary to know the dependence of the crop on the integrated characteristics of soil-water regime. We propose the following parameter for this aim:the quantity of day in which we have the magnitude of P≤Pcr at the depth established. We investigated the dependence of crop on this integrated parameter for 2,3rd year luzern. This dependence is close to the directly inversely proportional one (fig.2).This dependence allows us to use the information on the dynamics of soil matric pressure in the models of water management and crop productivity. Thus, the magnitude of Pcr as a hydrological parameter, can be used in different kinds of prognosis models.

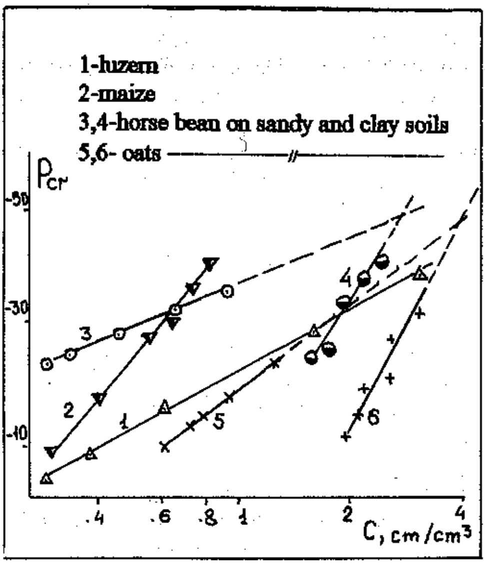

Fig.1.The critical pressures (Pcr,kPa) change depending root concentration (C,cm/cm3).

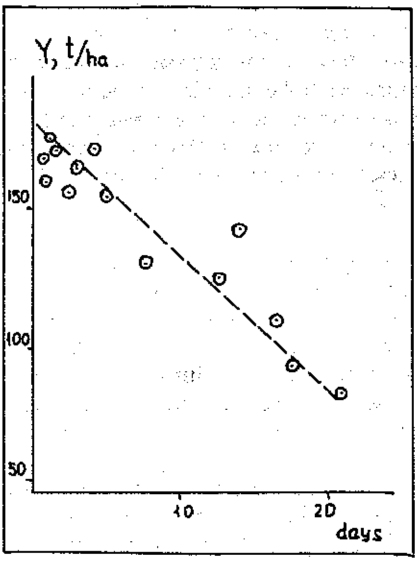

Fig.2.The dependence ofluzern crop (Y,t/ha) on the quantity of days with P<Pcr

CONCLUSIONS

Critical pressure (Pcr), which depends on soil and plant properties is the main parameter of water availability to plants and water plant nutrition.This Pcr is equal to the matric pressure, when the relative transpiration becomes lower than 1.Pcr also depends on the root concentration in a concrete soil layer. This dependence of Pcr on the root concentration in a soil layer is useful for models of water movement in soil.

The value of Pcr is also dependent on soil hydrological conditions:in soils with shallow water table it is necessary to establish the depth of observation, because of the non-uniform soil-water pressure profile. For the management and productivity models it is proposed that the parameter of water regime on the basis of Pcr should be used: the quantity of days when P<Pcr at the depth established. The crop of luzern is in direct inverse proportion to this integrated parameter of water regime in soil.

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A LONG-TERM COMPARISON OF PLOUGHING AND SHALLOW TILLAGE ON THE YIELD OF SPRING CEREALS IN FINLAND

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ABSTRACT

A long-term (1979-1992) field experiment was conducted in southern Finland to evaluate the effect of shallow tillage, as well as different straw management and weed control on the yields of spring cereals. Overall, shallow tillage seemed to provide an alternative to conventional autumn ploughing in spring cereal cultivation. On average, shallow tillage produced equal or greater yields than ploughing on clay and loam soils, when couch grass (*Elytrigia repens*) was controlled succesfully. On fine sand soil, the proliferation of couch grass reduced considerably the yields in shallow tillage.

Generally, wet seasons favoured autumn ploughing and dry seasons shallow tillage. Evidently, shallow tillage improved water conservation after sowing by reducing evaporation and surface slaking. The compaction of topsoil in shallow tillage may have resulted in the yield cuts during rainy seasons. However, the results from a well drained clay loam soil suggested, that there may have been a certain transition period, after which shallow tilled soil became less sensitive to wet seasons. Continuous macropores, including earthworm burrows, apparently counteracted the effect of the increased bulk density and penetration resistance in the toplayer of unploughed soil.

Although crop residues caused problems in seedbed preparation and sowing with conventional implements, the incorporation of straw seemed to be a better alternative than removing straw, especially on soils with high clay content. Obviously, shallow incorporation of residues enhanced the beneficial effect of shallow tillage on soil structure.

INTRODUCTION

Farmers in Finland have been increasingly interested in shallow tillage, in which the conventional autumn ploughing is replaced by stubble cultivation. One reason for this has been the growing need to reduce costs. Also, the advances in herbicide technology and improvements in tillage implements has made it possible to control weeds and manage crop residues without intensive tillage. The potential of shallow tillage in water conservation during dry seasons has also encouraged farmers to adopt new tillage systems. More recently, the growing concern about the eutrophication of surface waters caused by soil erosion and phosphorus runoff has hastened the efforts to introduce tillage systems, in which fields are not as susceptible to erosion as in conventional tillage. So far, there have been fairly few long-term studies of shallow tillage on different soils in Finland (1). The purpose of this study was to evaluate the effect of shallow tillage, as well as different straw management and weed control on the yields of spring cereals in a long-term field experiment (1979-1992) at six locations in southern Finland.

MATERIALS AND METHODS

The experiment was started in the autumn of 1979 in Jokioinen (clay loam), Pälkäne (fine sand), Anjalankoski (silty clay), Kokemäki (loam), Mouhijärvi (loam) and Mietoinen (heavy clay) (table 1). The original experimental layout was a strip-split-plot with factors as follows, chemical couch grass (*Elytrigia repens*) control with glyphosate (superior plot): no spraying (NG) and glyphosate spraying every 3-4 autumn (HG); primary tillage (main plot): autumn ploughing (P), autumn stubble cultivation (AC) and spring stubble cultivation (SC); straw management (sub-plot): straw chopped and incorporated (S) or straw removed after harvest (NS). In Anjalankoski the HG treatment was omitted, and the experimental layout was a split-plot. In 1989, the experiment in Pälkäne was terminated, and at the rest of the sites the experimental layout was modified by treating all the plots with glyphosate and by leaving straw also on the former NS plots.

Table 1. The experimental sites: soil texture and type, depth of primary tillage and crops.

Site	Texture & soil type[1]	Depth of primary tillage (cm) and implement used[2]		Crops during the research period 1980-1992[3]
		Ploughing	Stubble cult.	
Jokioinen	42-22-17-19 clay loam	20 MB	10-12 FC	w,o,b,w,o,b,w,o,b,b, o,b,w
Pälkäne	6-8-15-71 fine sand	26 MB	8-10 RSH	b,w,o,b,w,b,o,b,o,b
Anjalankoski	48-35-12-5 silty clay	23 MB	8-10 RSH	w,o,b,w,o,b,w,o,o,b, b,b
Kokemäki	27-36-16-21 loam	26 MB	8-10 RSH	w,o,b,b,w,b,b,o,b,w, b,w,o
Mouhijärvi	29-47-12-12 loam	23 MB	8-10 RSH	b,w,o,b,o,b,w,o,b,b, o,b,w
Mietoinen	63-22-6-9 heavy clay	23 MB	10-12 FC	w,o,b,o,w,o,b,w,o,b, w,o,b

1 clay - silt - fine sand - coarser (%, size limits 0.002 - 0.02 - 0.06 mm, respectively).
2 MB=mouldboard plough, FC=field cultivator, RSH=rotary spade harrow.
3 w=spring wheat, o=spring oats, b=spring barley.

Autumn ploughing was done with a mouldboard plough, and stubble cultivation either with a field cultivator or rotary spade harrow. Seedbed preparation and sowing of spring cereals were carried out using conventional s-tine harrows and combined seed and fertilizer drills (12.5 cm seedrow spacing). Spring wheat, spring oats and spring barley were grown in a non-regular rotation. A compound fertilizer (N-P-K) was placed between every second seedrow to a depth of 8 cm. Plots received annually 80-100 kg ha^{-1} inorganic N.

For this study the yield results were averaged over the experimental years for each site, and analyzed by ANOVA. The effect of the straw management on yields was tested for the first ten experimental years, when straw was removed from the NS plots. A linear regression analysis was conducted to test the effect of summer rainfall on the yield difference between shallow tilled and ploughed soils. Only HG plots were taken into this analysis.

RESULTS AND DISCUSSION

Tillage and weed control

On average, both autumn and spring stubble cultivation produced similar yields than ploughing on clay loam, silty clay, loam and heavy clay soils. On the fine sand soil in Pälkäne shallow tillage reduced significantly the average yields (table 2).

Table 2. Grain yields (kg ha^{-1}) after different tillage and glyphosate treatments. The yield was not harvested in 1987 and 1992 at Mietoinen and Anjalankoski, respectively.

Site	Years of harvest	Tillage[1]	Couch grass control[2] NG	HG	Average tillage	Significance NG vs. HG[4]
Jokioinen clay loam	13	P	4060a[3]	3970a	4010a	ns
		AC	4040a	4110a	4080a	
		SC	3810b	4160a	3990a	
Pälkäne fine sand	10	P	3760a	3780a	3770a	**
		AC	3350b	3670ab	3510b	
		SC	2760c	3610b	3190c	
Anjalankoski silty clay	12	P	2390a	--	2390a	--
		AC	2300a	--	2300a	
		SC	2490a	--	2490a	
Kokemäki loam	13	P	3920a	3900a	3910a	ns
		AC	3930a	3960a	3950a	
		SC	3860a	3970a	3910a	
Mouhijärvi loam	13	P	3110a	2970a	3040a	ns
		AC	2930a	3060a	2990a	
		SC	3080a	3180a	3130a	
Mietoinen heavy clay	12	P	3350a	3430a	3390a	*
		AC	3270a	3490a	3380a	
		SC	3270a	3630a	3450a	

1 P=autumn ploughing, AC=autumn stubble cultivation, SC=spring stubble cultivation

2 NG=no glyphosate spraying (Pälkäne) or one glyphosate application in the autumn of 1989 (the other sites), HG=glyphosate sprayig every 3-4 autumn.

3 in each column, the values within sites are significantly different (Tukey's test at 5% level) when not followed by the same letter.

4 significance levels: *P<0.05, **P<0.01.

The regular couch grass control with glyphosate increased the yields considerably on unploughed soil, and the average yields were greater in shallow tillage than in conventional tillage in Jokioinen, Kokemäki, Mouhijärvi and Mietoinen. The yield increase was more pronounced on the spring stubble cultivated soils.

The results clearly showed the importance of the proper control of couch grass in spring cereal cultivation. Overall, shallow tillage seemed to control couch grass less effectively than conventional tillage. However, the experiment in Anjalankoski showed that if there was no couch grass on the field at the start of the experiment, this weed did not cause any marked problems in shallow tillage. At the other sites, there were fairly large amounts of couch grass present at the beginning of the experiment, and the weed proliferation was rapid, particularly on the lighter soils with spring stubble cultivation. The weed problem was worst on the fine sand soil.

Autumn stubble cultivation seemed to control couch grass more effectively than spring stubble cultivation. Depending on the weather conditions in autumn, the mechanical weed control may considerably disturb the growth of couch grass. If no tillage is done in autumn, couch grass has plenty of time to expand in autumn after harvest, and again in spring before the sowing time.

Effect of the growing season

The yields varied rather strongly from year to year. Generally, very wet growing seasons favoured autumn ploughing and dry seasons shallow tillage. Spring stubble cultivation seemed to be more sensitive to wet seasons than autumn stubble cultivation. However, if the season was very dry the SC treatment usually produced the highest yield. The June rainfall explained significantly the yield difference between shallow tilled and ploughed soil in Jokioinen, Kokemäki, Mouhijärvi and Mietoinen. The trend is shown for Jokioinen and Mietoinen in figure 1. The rainfall in May or July did not have effect on the yield difference. Similar, but not significant trend was observed on the silty clay soil in Anjalankoski. On the fine sand soil, the yield difference could not be explained with the summer rainfall.

Evidently, shallow tillage improved water conservation after sowing on clay and loam soils. The measurements of soil moisture in 1989-1992 showed that ploughed soil dried more rapidly after sowing than shallow tilled soils. Better aggregate stability and higher organic matter content (2), and the undecayed residues on soil surface apparently reduced evaporation and surface slaking, which usually accelerates evaporation. This result agrees with those of Rydberg (3), who observed that shallow tillage reduced evaporation mainly by reducing slaking of soil surface.

Particularly on soils with high clay content, shallow tillage produced lower yields when the season was very wet. The measurements of soil bulk density and penetration resistance after six experimental years showed that the topsoil was more compact in the shallow tilled than in ploughed soil (2). This may have resulted in lower infiltration, and subsequently, yield losses during wet seasons. The yield results from the well drained clay loam soil suggested, however, that there may have been a certain transition period, after which shallow tilled soil became less sensitive to wet seasons. The first half of 1980's was fairly rainy, and shallow tillage produced lower yields than conventional tillage. Later, the seasons 1987 and 1991 were also wet, but no clear yield cut was observed on this soil. The poorly drained heavy clay and silty clay soils did not behave similarly than the clay loam.

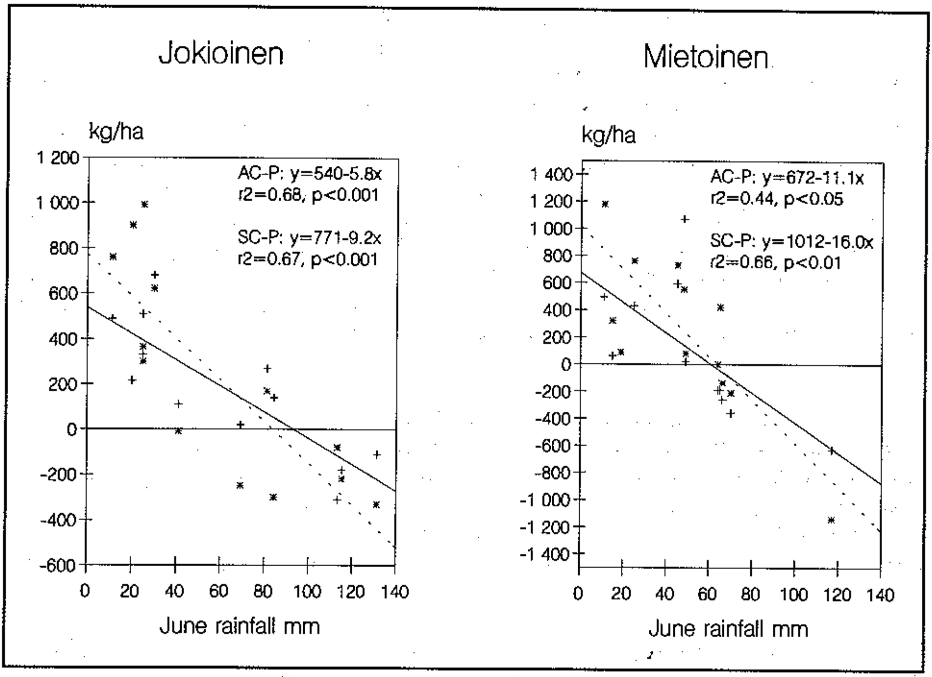

Fig. 1. The effect of June rainfall on the yield difference between shallow tilled and ploughed soils in Jokioinen (clay loam) and Mietoinen (heavy clay). The solid regression line is for the yield difference between autumn stubble cultivated (AC) and ploughed (P) soil (single observations are marked by "+"). The dotted line is for the yield difference between spring cultivated (SC) and ploughed soil (single observation are marked by "*"). The normal rainfall in June (1961-1990) is 47 mm in Jokioinen, and 44 mm in Mietoinen.

After ten years the macropore (Ø>1 mm) density in the topsoil-subsoil interface was usually markedly higher in shallow tilled than in ploughed soils (4). Most of these macropores were earthworm burrows, and Nuutinen (5) observed an increased number of deep burrowing earthworms under shallow tillage. The higher number of burrows in the topsoil and upper subsoil of unploughed treatments may contribute beneficially to infiltration (6,7), and also act as preferential pathways for plant roots (8). These factors may counteract the higher compactness measured in the top layer of unploughed soil. A functioning drainage seemed to be essential to gain these changes in soil structure. In the poorly drained clay soils the number of burrows was considerably lower than on the clay loam soil.

Straw management

On the two loam soils and the fine sand soil the straw removal increased, although not significantly, the average yields on the unploughed plots (data not shown). This effect was usually pronounced on the SC treatments. On the contrary, on soils with high clay content the removing of straw decreased the average yields, significantly in Anjalankoski and Mietoinen. Generally, the straw management did not seem to have any apparent effect on the yields when soil was autumn ploughed.

On unploughed soil, surface straw and stubble caused mechanical blockage of the conventional s-tine harrows and seed drills, especially on the light loam and fine sand soils. This usually resulted in an uneven establisment of plants. The straw problem was pronounced on the spring stubble cultivated plots, when there were large amounts of straw (after oats), or stubble was high. The residue cover on soil surface also delayed the drying and warming of SC plots. On autumn stubble cultivated plots, residues were more decayed, which usually reduced the problems in spring. On soils with high clay content, the amount of straw was nsually lower, and tillage and sowing machinery seemed to cope better with residues than on lighter soils. Nevertheless, it must be emphasized here, that also on the clay soils straw and stubble sometimes impeded the implements in secondary tillage and sowing. Particularly, the SC plots often required greater number of passes in seedbed preparation than the other treatments. This, together with the fact that the residue cover kept the soil moister on SC plots, increased the risk of compaction.

The effect of shallow residue incorporation on soil structure may be the major reason to the yield increase on clay soils. The measurements made after six experimental years showed that the organic carbon content in the topsoil was 0.1-0.3 percentage units higher, and the aggregate stability of seedbed considerably better on the unploughed plots with residue incorporation than on the plots with straw removal (2). After ten years there were significantly more macropores in the topsoil and upper subsoil when straw was incorporated compared with the NS treatment (4).

From the standpoint of practical farming straw removal usually means extra work and costs. Burning of straw in a larger scale is not a real alternative for residue disposal. Thus, a sufficient chopping and spreading of straw, combined afterwards with effective incorporation seems to be the only rational way to manage residues in shallow tillage. Stubble should be left as short as possible. Residue incorporation in the autumn is usually necessary, particularly if the amount of residues is large, to avoid the problems with seedbed preparation and sowing in spring.

CONCLUSIONS

In this experiment shallow tillage produced equal or greater spring cereal yields than conventional ploughing on clay and loam soils, when couch grass was controlled succesfully. The results showed clearly the importance of the proper control of couch grass infestation in shallow tillage. Both mechanical and chemical measures were usually needed to prevent the proliferation of couch grass.

Generally, wet seasons favoured conventional tillage and dry seasons shallow tillage. Evidently, shallow tillage improved water conservation after sowing by reducing evaporation and surface slaking. The compaction of topsoil in shallow tillage may have resulted in the yield cuts during rainy seasons. However, continuous macropores, including earthworm channels, may have counteracted the higher compactness measured in the toplayer of shallow tilled soil.

Although crop residues caused problems in seedbed preparation and sowing, the shallow incorporation of straw seemed to be a better alternative than removing straw, especially on the soils with high clay content. Obviously, shallow incorporation of residues enhanced the beneficial effect of shallow tillage on soil structure.

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THE EFFECT ON SOIL PROPERTIES AND CROP YIELD OF PLOUGHING DEPTH AND SEEDBED PREPARATION FROM 1940 TO 1990 ON A LOAM SOIL IN SOUTHEASTERN NORWAY

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ABSTRACT

Ploughing depths, seedbed preparation and nitrogen fertilization were investigated on a loam soil at Ås, Norway. The experiment was established in the autumn of 1939 and reorganized in 1962. The working depths for ploughing (12, 18 and 24 cm) and seedbed cultivation (4, 8 and 12 cm) were constant during the whole research period. Treatments of nitrogen application rates (50, 100, 150 kg ha^{-1}) and seedbed preparation implements (S-tine and rotary cultivator) were superimposed in factorial configuration upon the experiment in 1962. Since 1962 the main crops were barley, oats and ley (timothy + red clover).

The yield loss for shallow ploughing (12 cm) was most pronounced in years with high weed infestation and at low nitrogen application rate (50 kg ha^{-1}). Shallow harrowing with S-tine cultivator (4 cm, one pass) significantly reduced cereal yields compared with more intensive and deeper cultivation.

The soil structure measured from 1968 to 1987 appeared to be slightly better with regard to plant growth requirements after shallow (12 cm) as compared to deep (24 cm) ploughing. The amount of organic matter in 0-40 cm depth was not influenced by ploughing depth. However, the content of organic matter in the surface layer (0-12 cm) was higher after shallow ploughing.

INTRODUCTION

After the second agricultural revolution, ploughing with the steel mouldboard plough became the common cultivation practice in temperate regions. The ploughing depth increased gradually, partly as a result of more available power for tillage, partly as a belief in greater effects against weeds. In Norway Hasund (1), Hasund and Saltrøe (2), Saltrøe (3) and Njøs and Ekeberg (4) did not find any significant effects of ploughing depth on yields. Annual and long-term experiments in Sweden showed about the same yields for shallow (12 cm) and deep ploughing (20-25 cm) (5, 6). In England increased ploughing depth increased sugar beet yields, but for cereals the results varied (7, 8). They observed that shallow ploughing produced more weeds than deep ploughing.

During 51 years data were systematicaly collected at the Agricultural University of Norway with the intention to investigate the long-term effect of ploughing depth, seedbed cultivation intensity and nitrogen application rate on crop yields and soil properties.

MATERIALS AND METHODS

Soil characteristics

The soil was a loam (0-85 cm) and was classified as a fluvaquentic humaquept (9).

Experimental design and treatments

The experiment was started in the autumn of 1939. Soil treatment includued: Ploughing with mouldboard plough in autumn; I: 12 cm depth, II: 18 cm depth and III: 24 cm depth. Seedbed cultivation in spring; a: Tine cultivator to 4 cm, one pass, b: to 8 cm, two passes, c: to 12 cm depth, three passes, d: Rotavator to 4 cm, one pass, e: to 8 cm, one pass and f: to 12 cm depth, one pass. Nitrogen application rate (calcium nitrate); N1: 50, N2: 100 and N3: 150 kg per hectare. The rotavator and nitrogen treatments were added to the experimental design in 1962. The working depths for both ploughing and seedbed cultivation have been constant since 1939.

Crops

From 1940 to 1961 two different crop rotations, both with arable crops and ley were carried out. Crops grown after 1962 were mainly spring barley (Hordeum vulgare L.) and spring oats (Avena sativa L.). Grass (timothy (Phleum pratense L.) + red clover (Trifolium pratense L.)) was grown in 1968, 1969, 1970, 1976, 1977, 1983 and 1984. The yields were assessed as kg per hectare with 15 g $100g^{-1}$ moisture content as well as feed fattening units per hectare. One feed fattening unit is equivalent to 1 kg barley.

RESULTS AND DISCUSSION

Crop yields

Yields for the different ploughing depths during the 51 years research period are given as cumulative yield differences in feed fattening units (FFU) in Fig. 1. Compared to a normal ploughing depth of 18 cm, deep ploughing generally gave 60 FFU ha^{-1} y^{-1} greater yield, and shallow ploughing resulted in 80 FFU ha^{-1} y^{-1} less yield. During the period 1978 to 1980, the yields decreased significantly for shallow ploughing, but thereafter yields were slightly increased compared to normal ploughing depth. The small effect on yields after 1981 corresponded to the glyphosate treatment of the field in autumn 1981. The most pronounced yield decrease by shallow ploughing occurred during the period 1978-1980, probably caused by higher weed infestation after the two dry years 1975 and 1976..

From 1962 the tillage treatments were combined with three nitrogen application rates. Cumulative grain yield differences for the lowest and highest nitrogen application rate are shown in Fig. 2. At low nitrogen application rate shallow ploughing reduced the cereal yields almost every year during the research period. At higher nitrogen levels grain yields were significantly reduced only during the period 1978-1981. This interaction between ploughing depth and nitrogen fertilization is consistent with Kahnt (10), but in our long-term experiment the effect of deeper ploughing than 18 cm seemed to be small.

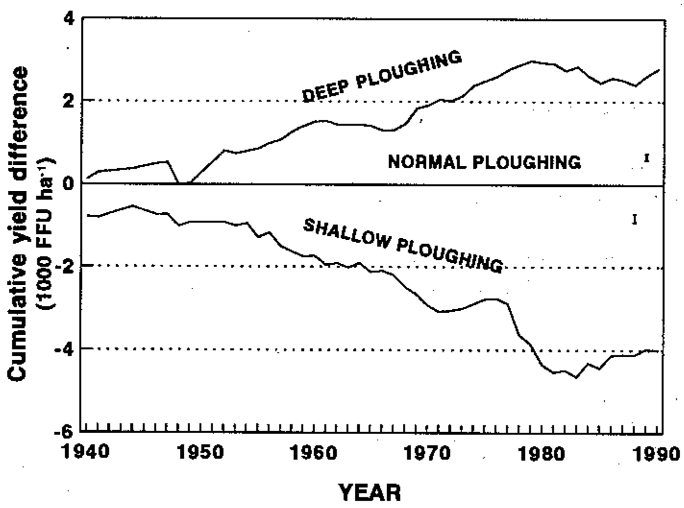

Figure 1. Cumulative yield differences as feed fattening units (1000 FFU ha^{-1}) for three ploughing depths during the period 1940-1990. Reference: Normal ploughing (18 cm). Error bars indicate standard deviation for the annual yield differences for the research period.

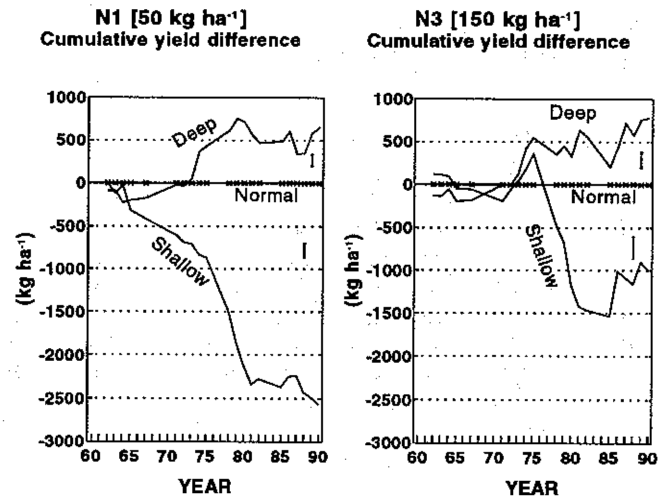

Figure 2. Cumulative grain yield differences (kg ha^{-1}) for three ploughing depths and two nitrogen application rates during the period 1962-1990. Reference: Normal ploughing (18 cm). Error bars indicate standard deviation for the annual yield differences for the research period. Asterisks on the line for normal ploughing depth indicate the years with cereals crops.

Seedbed preparation treatments during the period from 1962 to 1990 showed that in many years one pass with the S-tine cultivator to 4 cm depth produced significantly lower yields as compared to the five other seedbed preparation treatments (not shown in any table or figure). To achieve yields similar to results from one pass with rotavator to 4 cm, the S-tine cultivator had to be used twice, i.e. 8 cm depth during the second pass. Three passes with the S-tine cultivator, with 12 cm depth during the last pass, increased the yields slightly more than two passes with 8 cm final depth. One pass with the rotavator to 8 cm depth gave the highest yield on the average during the research period. However, for the years 1978-1981 the yields increased more than earlier when the intensity and depth of seedbed preparation increased. These years corresponded with the dramatic yield decreases for shallow ploughing. Therefore it is to be expected that part of the explanation must be related to weeds (see Table 2 and 3). Another problem with shallow harrowing (4 cm, one pass) by a cultivator was to achieve the right sowing depth and a good covering of the seeds.

3.2 Soil properties

The soil volumetric relationships in the layer 7-11 cm are shown in Fig. 3. Data are mean values for the years 1968, 1973, 1978, 1983 and 1987. Soil porosity was decreased as the ploughing depth was increased. It was mainly the air conducting pores (>30 μm) which decreased with increased ploughing depth. Waterholding capacity (pores 0.2-30 μm) was greatest for shallow (12 cm) and least for deep ploughing (24 cm). The main contribution to this difference was found in the pore size range of 0.2-3 μm.

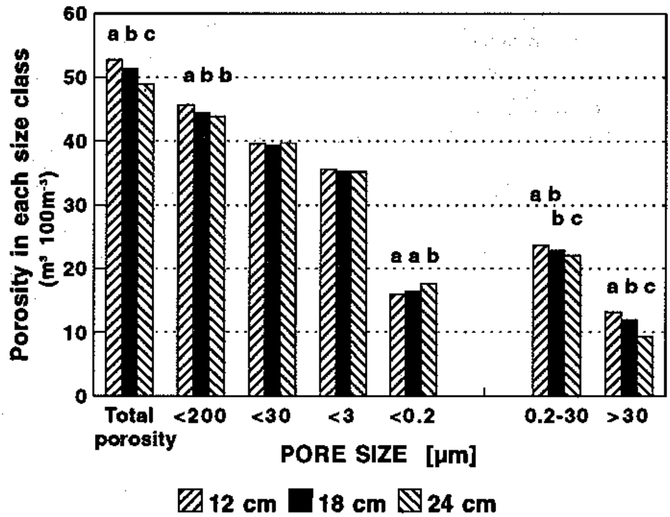

Figure 3. Porosity and distribution of porosity in various size classes (m^3 $100m^{-3}$) averaged over the years 1968, 1973, 1978, 1983 and 1987 for three ploughing depths for the layer 7-11 cm. Air porosity is indicated by pores >30μm. Treatments that differ significantly (P<0.05) are indicated by different letters.

Modulus of rupture in 7-11 and 13-17 cm depth measured in 1983 is given in Table 1. Modulus of rupture increased significantly with ploughing depth. The results are partially explained by the organic matter content which increased with decreased ploughing depths.

Table 1 Modulus of rupture (kPa) in two layers for three ploughing depths for 1983. Values that differ significantly (P<0.05) are indicated by different superscripts

Sampling depth (cm)	Ploughing depth (cm) 12	18	24
7-11	13.9[a]	16.0[a]	26.1[b]
13-17	16.4[a]	21.6[b]	28.0[c]

Based on data from 1987 the effect of ploughing depth on the mass of organic matter in kg per hectare was calculated for each horizon (Fig. 4). The amount of organic matter in the layer 0-12 and 12-18 cm were significantly higher for shallow compared to deep ploughing. In the layer 24-40 cm the deep ploughing (24 cm) had a greater amount of organic matter than the other ploughing depths. The amount of organic matter in the 0–40 cm profile was not significantly influenced by the ploughing depths. After shallow ploughing more organic matter was concentrated near the soil surface. However, the difference in amount of organic matter down to 40 cm was not more than about 200 kg ha^{-1} for the three ploughing treatments.

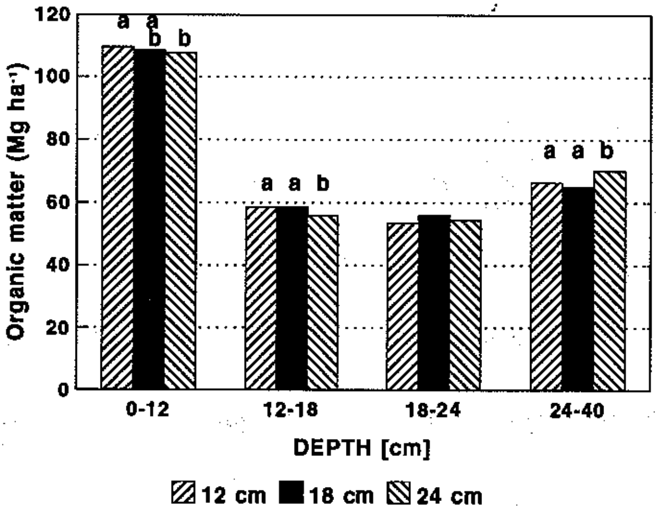

Figure 4. Organic matter (Mg ha^{-1}) for three ploughing depths in four soil layers calculated after measurements in 1987. Treatments that differ significantly (P<0.05) are indicated by different letters.

CONCLUSIONS

This experiment showed that shallow ploughing gave as good yields as deeper ploughing if the weeds were under control and nitrogen application at least 100 kg ha^{-1}. Harrowing to 4 cm with S-tine cultivator reduced yields significantly compared with the other treatments. This effect was most evident in combination with shallow ploughing and during periods of high weed infestation.

The soil properties were influenced by ploughing depth. The soil structure measured as bulk density, porosity, air porosity, pore size distribution and aggregate stability was slightly more favourable to plant growth after shallow ploughing (12 cm), as compared to normal (18 cm) and deep (24 cm) ploughing. Modulus of rupture increased significantly with increasing depth of ploughing.

The amount of organic matter in the upper 40 cm of the soil profile was not affected by ploughing depth. However, the content of organic matter in the surface layer was higher after shallow as compared to deeper ploughing.

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LONG TERM EFFECTS OF PLOUGHLESS TILLAGE ON SOIL CHEMICAL PROPERTIES AND CROP YIELDS

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ABSTRACT

Deep chiselling (25-30 cm), shallow cultivation (10-15 cm) and minimum tillage (7-10 cm) are compared with mouldboard ploughing since 1969 in a 27 % clay soil. Winter wheat, winter rape, winter wheat and grain maize are grown in crop rotation. The wheat straw is baled off while rape and maize stalks are chopped. Two nitrogen levels are applied as secondary treatments to the tillage.
All three ploughless technics can be recommended to farmers as sustainable tillage operations as far as soil chemical properties and crop yields are concerned. In Switzerland, considering the rather small scale of our farms, our tillage philosophy is to promote the idea of alternating ploughing and ploughless soil tillage in integrated farming. The choice of tillage depth and implement depends on the state of the soil condition after harvest, on the crop rotation and on phytosanitary aspects, such as weed, volunteers, disease or slug control.

INTRODUCTION

Short term tillage experiments in Switzerland have shown at least two real benefits from ploughless cultivation. Firstly, farmers can save time, fuel and money (1, 2, 3 and 4). Secondly, soil degradation, especially erosion can be reduced , if not completely controlled (5 and 6). Short term experiences are however inappropriate to answer farmers' questions on the long term effect of ploughless tillage. Results from long term tillage trials at Changins have been published in the past (7, 8 and 9). The objective of this paper is to present some results of another long term trial that started in 1969 and that is still going on (10 and 11).

MATERIALS AND METHODS

- Tillage treatments :
  1) Plough 20-25 cm ;
  2) Chisel 25-30 cm;
  3) Cultivator 10-15 cm ;
  4) Rotovator 7-10 cm.
- The final seed bed has been prepared in treatments 1 to 3 with the same rotovator used in treatment 4.
- Secondary treatments : N1 = 100 kg N/ha ; N2 = 130 kg N/ha
- Crop rotation : Winter wheat - Winter rape - Winter wheat - Grain maize
- Crop residues : Wheat straw baled off ; rape and maize stalks chopped

- Soil type : 27 % clay ; 44 % silt ; 19 % sand ; 2,40 organic matter (in 1969)
- Trial design : Split plot with 4 replicates
- Plot size : 160 m2 (8 x 20 m)

RESULTS AND DISCUSSION

Soil chemical properties

The data in figures 1 to 4 shows that , opposed to ploughing , all ploughless tillage technics led to a light acidification and an accumulation of organic matter, phosphorus and potassium in the top soil (0-10 cm) . The differences were gradually increasing from chiselling to rotovating. This is related to the tillage depth mentioned above. In the deeper soil layer (10 to 20 cm), soil chemical properties were less affected by the different tillage treatments. Unlike the data for the top soil, the P, K and O.M. content in the 10 to 20 cm deep layer was slightly decreased by the ploughless tillage operations .

Crop yields

Figure 5 represents the means of 5 harvests per crop. All continuously ploughless tilled plots produced similar or even slightly higher grain yields than the ploughed ones. No interaction occurred between the tillage treatments and the nitrogen levels.

CONCLUSIONS

- Deep chiselling, shallow cultivation and minimum rotovating continuously applied since more than 20 years did not affect negatively the soil properties nor the crop yields. Each of these ploughless technics can be qualified as a sustainable tillage operation and recommended to farmers . The success of the long term ploughless tillage depends mainly on good water infiltration in the soil as reported by other authors.

- The shallow cultivation (15 cm deep) was the most appropriate ploughless operation in our multiple crop rotation in terms of seed bed quality , volunteers and weed control.

- The ploughless tilled plots did not have to be fertilized with higher amounts of nitrogen than the ploughed ones.

- As part of our integrated farming concept , we do not recommend to swiss farmers continuous ploughless tillage but an alternation of ploughing and non ploughing. For the crop rotation presented in this trial (Winter wheat - Winter rape - Winter wheat - Grain maize), we recommend to plough (20-25 cm deep) once after harvesting maize , before sowing winter wheat. Maize yields are depressed by damages caused by the european stem borer (*Ostrinia nubulalis)*. Former tillage researches had shown that ploughing down the maize stalks in an efficient way to stop the multiplication of this insect. For the other crops, shallow cultivation (15 cm deep) is appropriate.

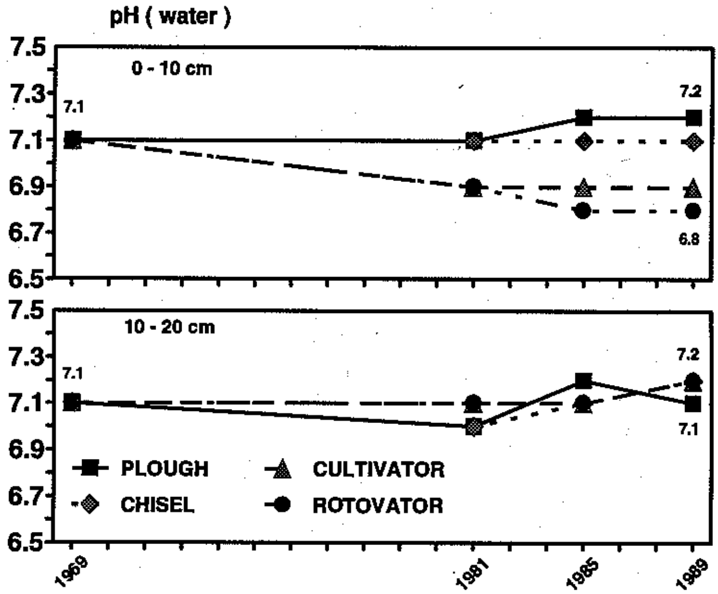

Fig. 1. Influence of tillage on soil acidity at two different depth (pH - water)

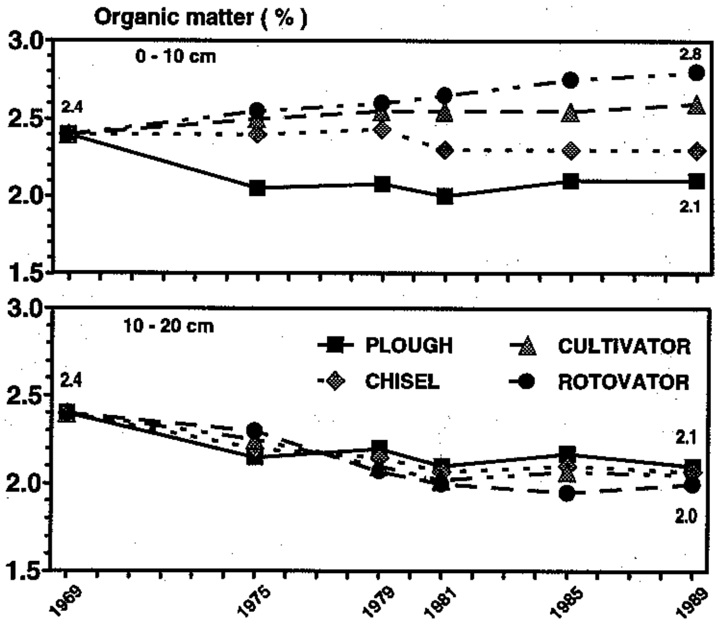

Fig. 2. Influence of tillage on the organic matter content of the soil at two depths (% OM)

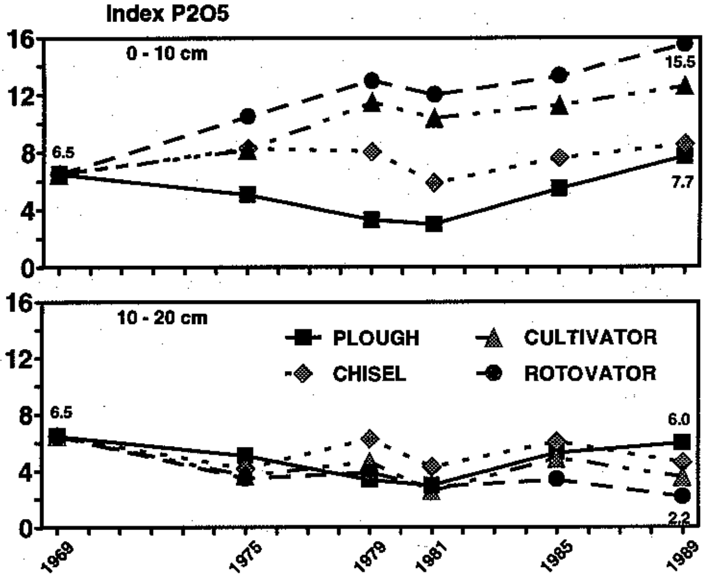

Fig. 3. Influence of tillage on the content of phosphorus in the soil at two depths (Index 1 = 0,0356 mg P_2O_5 / 100 g)

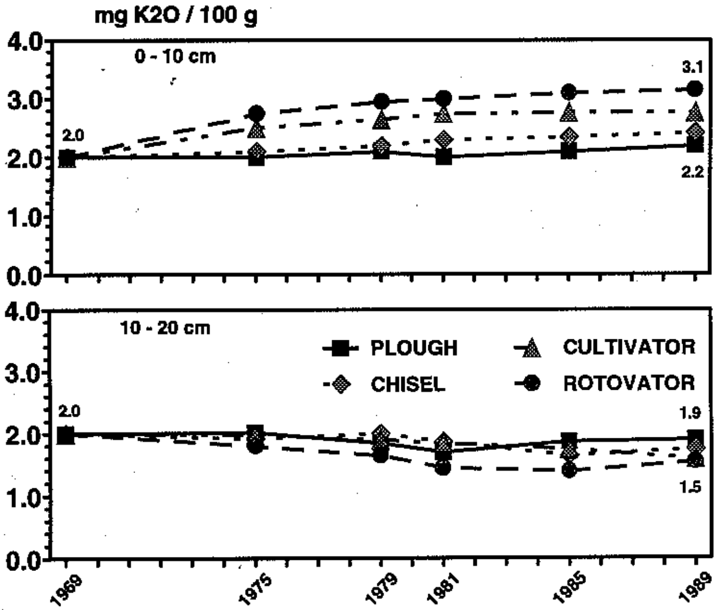

Fig. 4. Influence of tillage on the content of potassium in the soil at two depths (mg K_2O / 100 g)

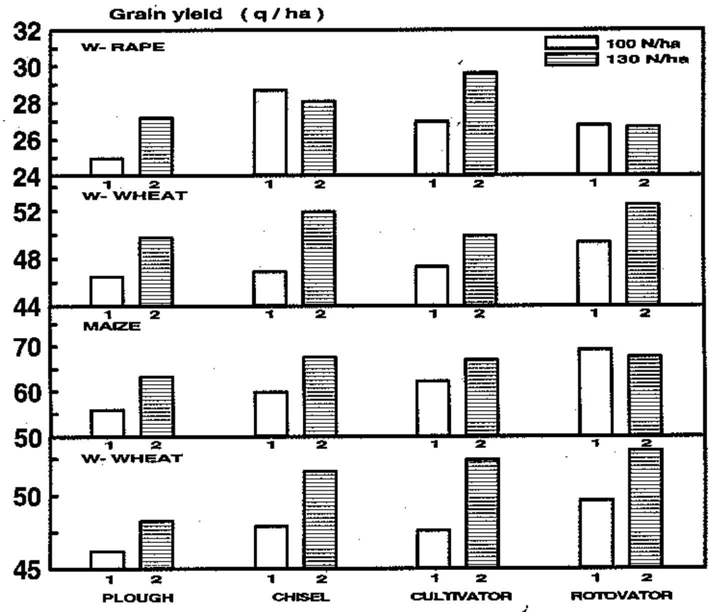

Fig. 5. Influence of tillage on grain yields of winter rape, winter wheat, maize and winter wheat at two nitrogen levels (q/ha). Means of 5 harvests per crop.

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RESEARCH IN CROPPING SYSTEMS IN DENMARK. THE DESIGN AND EVOLUTION OF AN INTEGRATED STRATEGY FOR CROPPING SYSTEMS WITH SPECIAL ATTENTION ON SOIL TILLAGE AND UTILIZATION OF ORGANIC MATTER.

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ABSTRACT

Research in cropping systems is placed at three state research stations. Research Centre Foulum, Research Station Oedum and Research Station Jyndevad. Integrated and ecological crop rotations are, since 1987, established in fields at about 1 ha and the research is carried out under a holistic approach.
Every field is divided in a research area and a reference area.The design and results from 1987 will be present. From the integrated rotation results will be presented from a project with two levels of soil tillage, different combinations of straw, catch crops and liquid manure and up to four levels of nitrogen. Research design, strategies for soil tillage, fertilization and irrigation will be present. Weed and pest reactions in relation to the different treatments, yield, fertilization and interactions will be present, too. The lecture will be connected to a poster presentation of detailed results.

INTRODUCTION

Evolution of integrated farming takes place all over Europe (Vereijken, 1989). Guide lines for integrated farming have been produced (El Titi et al, 1993). Many research activities are coordinated through the IOBC working group for integrated farming systems.
In Denmark Research in Cropping Systems was started in 1987 and situated at three state research stations. Research Centre Foulum, Research Station Oedum and Research Station Jyndevad. Integrated and ecological crop rotations was established in fields at about 1 ha each.
The climatic conditions and soil types varies considerably in the different countries from the north to the south of Europe and detailed integrated cropping strategies must be produced for the single climatic area and related to the possible farming strategies. A good example is the possibility of using catch crops effectively.
In integrated farming in Denmark, there has been a lot of focus on nitrogen both as the main fertilizer for the production of high quality crops and as a polluting agent. Nitrate leaching has been emphasized, because all drinking water is ground water and the soils are mostly rather sandy. In addition the winters in Denmark have been warm and rainy recently causing higher nitrogen leaching. Soil tillage has played a minor role differing from most other European countries where soil tillage and possibilities to reduce soil tillage has been in focus mainly because of very heavy clay soils, soil erosion and a wish to become a higher direct

margin.
Research on integrated farming in Denmark has concentrated on the use of fertilizers, especially organic matter utilization from crop residues and liquid manures left in the field. It has been a main goal to reduce the environmental effects from nitrate leaching and gaseous nitrogen losses but also to use the organic matter resource for the biological processes in the agro ecosystem (Christensen, 1991). Soil tillage has then been part of an integrated strategy to conserve nitrogen.
In integrated farming the crop rotation is the most important factor to reduce input of fertilizers and pesticides. Through the rotation it is possible, more or less, to control nitrate leaching and to minimize the need for pesticides. Different strategies for soil tillage must be an integrated part of the rotation connected to the crops needs and as a factor to reduce the input factors.
This article focuses on the design of research in Cropping systems. The background and strategies for soil tillage as part in the nitrogen conserving goal in rotations where the main fertilizer is liquid animal manure.

METHODS

Research in Cropping Systems in Denmark is placed at three locations. Crop rotations and design are described in Mikkelsen and Mikkelsen (1989). The soil type at Foulum is a coarse sandy loam, at Oedum a fine sandy loam and at Jyndevad a coarse sandy soil. At each sites two integrated and one ecological rotation are situated. Every field is divided in two parts. A reference part with no plots for research and a research part.
In the reference part of the field a monitoring program evaluates the system influence on yield, crop quality, pests/diseases, fertilizer use, all input treatments with machinery, pesticide use and the soil mineral status. Yield and simple mineral balances are measured in four replicates in all crops every year. The measuring plots have a fixed position in each field and the size is 3.0m X 10.0m.
In the research part different projects takes place where the main goal is to evolve the system. For projects over long time periods a fixed position and plot size is chosen to secure results with no or little interference from other treatments in the long run.
In the integrated and ecological rotations there has been chosen a strategy for soil tillage. For all spring sown crops the ploughing is just before the seed bed preparation and in 20 cm depth. Animal manure is incorporated in spring by ploughing. For autumn sown crops the soil tillage is also ploughing to 20 cm. Liquid manure is spread in spring only.
To evaluate the systems in relation to conserving nitrogen there has in the integrated rotations dominated with grain been installed suction cells for soil water sampling. In addition the water balance is measured with tensiometres and by modelling (Olesen & Heidmann, 1990). In each field there are ten cells and the measurement is done every fortnight.
In the research area in the integrated grain rotations at Foulum, Oedum and Jyndevad a project was started 1988. Five levels of input of organic matter from catch crop, straw, and liquid manure was established in three replicates. Every organic matter level contains three levels of nitrogen where the top level is the recommended level for conventional farming and bottom level is 60% of top level. At Oedum and Jyndevad two organic matter levels are taken away and two different ploughing depths at 10 cm and 20 cm are established instead. Table 1 summarizes the treatments at the three different locations.

Table 1 Research plan for "Effects of green fields in long term dominated crop rotations". The + indicates the treatments at the concerned location. The two ploughing depths are at Oedum and Jyndevad, only.

Factor 1.

	%winter green fields		Foulum	Oedum		Jyndevad
	rotation mainly spring crops	rotation mainly winter crops	rotation mainly spring crops	rotation mainly spring crops	rotation mainly winter crops	rotation mainly spring crops
no org. matter	25	75	+	+	+	+
catch crop+ manure	75		+			
straw+ manure	45	90	+		+	
catch crop+ straw	90					+
catch crop+ straw+ manure	90		+	+		+

Factor 2.
a. Ploughing to 20 cm depth.
b. Ploughing to 10 cm depth.

Factor 3.
Nitrogen level:
x. recommended level
y. 80 %
z. 60 %

RESULTS

Results from these areas must be divided into two parts. Results from the research area where a statistical design is the background for the interpretation and results from the reference area where evaluation of system takes place. Here there is no replicates of the system and the evaluation must be based on trends in different parameters as time went on.

RESULTS FROM THE REFERENCE AREA

Figure 1 shows the input of nitrogen from liquid manure and output in the harvested crops. This simple nitrogen balance is from the ecological fodder crop rotation from 1992. The fertilization was done by liquid manure only, and the amount corresponded to one cow per hectare in average. Nitrogen fixation in clover grass and in barley/pea/rye grass (B/P/R) promotes a very high output of nitrogen. The rotations were established in 1987 and clover grass residues became a main fertilizer for the other crops in the rotation, as the years passed. In 1991, in the spring sown crops oat and barley, more nitrogen was harvested than total nitrogen input. In dry years the mineralization is low and the utilization of nitrogen from the soil organic pool is very small, as seen for 1992.

Figure 1. The input of nitrogen from liquid manure and the amount of nitrogen in the harvested crop is shown for 1992 in the ecological system. The crops involved are two years of clover grass, barley/pea/rye grass, barley, pea, beet and oat.

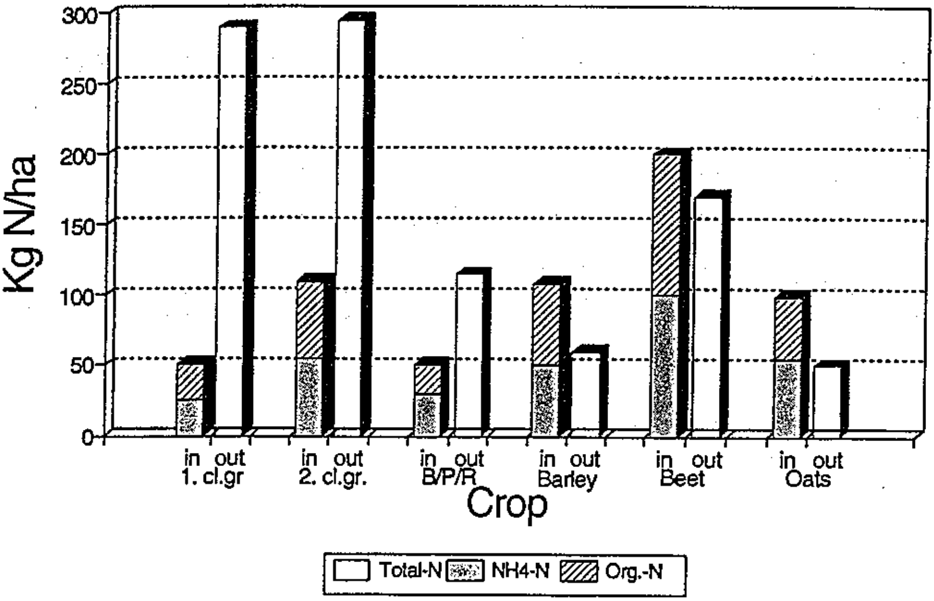
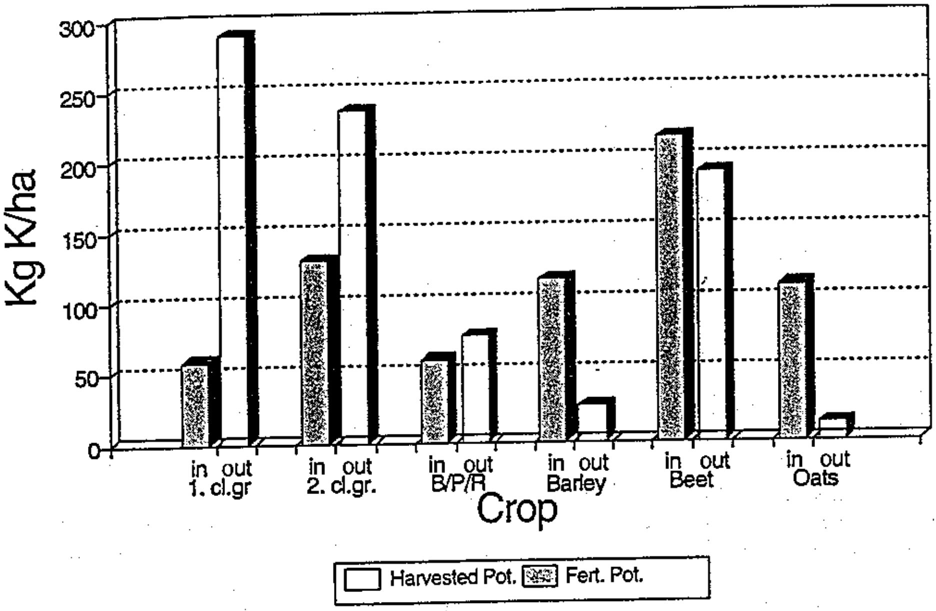


Figure 2 shows the input and output of potassium from 1992 in the ecological rotation. In most years more potassium is harvested than input from the liquid manure. In the long run potassium can be the limiting factor for the production.

Figure 2. The input of potassium from liquid manure and the amount of potassium in the harvested crop is shown for 1992 in the ecological system. The crops involved ar two years of clover grass, barley/pea/rye grass, barley, pea, beet and oat.



Fertilization in the integrated systems here is a combined use of liquid manure from cows and from ammonium nitrate. Uptake by the crops of P and K is full-filled from manure and ammonium nitrate is used as nitrogen fertilizer to a suboptimal level (80 % of the recommended). The utilization of nitrogen in average is the amount corresponding to the input of mineral nitrogen from the fertilizer sources.

RESULTS FROM THE RESEARCH AREA

At Oedum a project with a different ploughing depth and a different amount of organic matter input is situated . Detailed interpretation is given by Rasmussen and Hansen (1994)

Table 2. Yields of grain and potatoes in the crop rotations at Jyndevad and Oedum 1989-1993. Hkg grain with 85 pc. DM per hectare. Fresh weight of tubers in hkg per hectare.

CROPS	PLOUGHING 20 CM	PLOUGHING 10 CM	LSD	PLACE
Potato	507	487	s	Jyndevad
Winter rye	43,5	43,4	n.s.	Jyndevad
Spring barley	37,8	35,1	s	Jyndevad
Spring barley	42,8	41,3	s	Jyndevad
Winter barley	49,8	49,2	n.s.	Oedum
Winter rape	28,5	28,3	n.s.	Oedum
Winter wheat	76,4	77,5	n.s.	Oedum
Spring barley	45,3	43,5	n.s.	Oedum

DISCUSSION

In the evolution of systems for integrated and ecological farming it is important with detailed research in close connection to the system. Many subjects are to be studied to understand the interactions in the rotation and use them in evolving the system. Important areas are nitrogen balances in rotations, and crops where manure is the main fertilizer, and catch crops and grass fields serves as organic fertilizer for the system and research in a multi functional crop rotation where weed, pests and diseases are controlled without use of pesticides. Leaching of nutrients and how it can be controlled by use of winter green fields, fertilizer strategies and soil tillage systems is a main area of research too.

Looking at figure 1 from the ecological system input of organic matter from manure and clover grass fields to the soil organic pool serves a main fertilizer for the other crops in the rotation. The nitrogen fixation in clover grass serves both as a source for high quality fodder as well as nitrogen to the soil organic pool. The conservation of nitrogen in the rotation is very dependant on the timing of soil tillage and on winter green fields. In the ecological rotation (fig. 1) clover grass is spring ploughed and is followed by barley/pea/rye grass where rye grass remains until next spring and functions as a catch crop for mineralized nitrogen. In rotations with clover grass fields and animal manure as fertilizer it is difficult to reduce ploughing. Soil tillage is also a main factor in controlling weed especially in ecological farming systems. The loss of nitrogen to the environment is also very dependant of the timing of fertilization in relation to plant growth and soil tillage.

In the integrated rotations the amount of fertilizer nitrogen is planned as 100% utilization of the ammonium part of the liquid manure and ammonium nitrate is added to the level of 80% of the recommended level. In the grass crop in the fodder crop rotation the utilization of manure is low, because it is spread at the surface under dry conditions in summer. A better utilization is obtained using manure in crops where it can be incorporated immediately after spreading and then using industrial fertilizer in the grass fields.
The leaching of nitrate was kept at a low level especially in relation to the rather sandy soils in Denmark and in relation to the use of manure as fertilizer. In these rotations catch crops are used where possible and all straw is mulched. In such a investigation it is impossible to distinguish which field operations favouring leaching or keep the nitrogen in the plant soil environment.

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ADVANTAGES AND DISADVANTAGES OF NO-TILLAGE COMPARED TO CONVENTIONAL PLOUGH TILLAGE

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ABSTRACT

Reducing productiou costs and protecting soil have acquired keypositions in modern agriculture. Within a long-term soil tillage research project at the University in Giessen diverse ecological and economical advantages of no-tillage compared to conventional plough tillage have been realized. Results regarding investigations on aggregate stability, surface sealing, and fate of isoproturon in the soil are presented. Using no-tillage, one of the most important problems, namely straw management, is discussed.

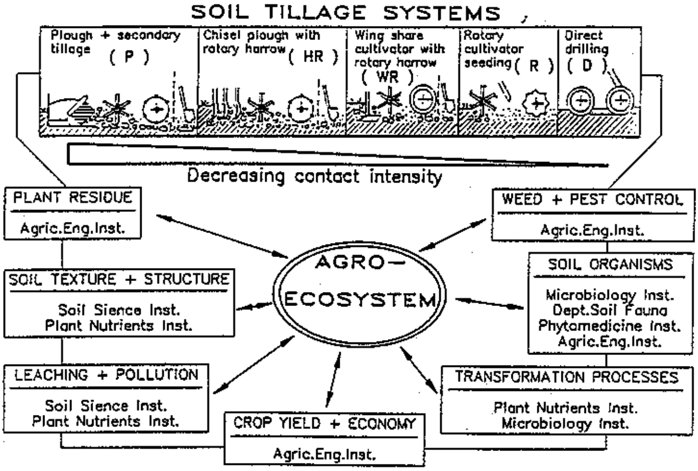


Figure 1: Interdisciplinary research on the interaction between soil tillage systems and the agro-ecosystem

INTRODUCTION

Due to recent EEC-agricultural policy negotiations the farmer is confronted with new basic conditions. Decreased incomes in crop production and the need for soil protection require to reconsider traditional management methods. With regard to ecological and economical aspects the discussion about conventional, conservation tillage systems, and no-tillage methods seems to be more and more important. Conservation tillage, especially no-tillage provide a chance to fulfil these actual requirements.

Within a long-term interdisciplinary research project at the University of Giessen the "Interactions of soil tillage systems and agro-ecosystem soil" were investigated (fig. 1). Soil structure, soil biology, plant diseases, weed abundance, leaching and decomposition processes, nutrition availability as well as the yields were examined. Beside these diverse aspects of plant production and soil ecology, economical criteria have been included in order to evaluate soil tillage systems (1).

RESULTS AND DISCUSSION

On the basis of the long-term soil tillage experiments, conducted since 1979, the following ecological and economical advantages of no-tillage compared to conventional plough tillage have been found:

- stable soil structure by building clay-humus-complexes
- higher population density of soil organisms (i.e. earth worm abundance, factor 4)
- higher straw decomposition rate (factor 4)
- higher microbiological activity
- higher load-capacity with proportionally less damage of soil structure
- higher infiltration capability
- lower tendency to soil erosion and surface sealing
- lower nitrate-leaching and herbicide-leaching
- lower infection with eyespot and take-all of cereals
- lower need of tractor power and working hours (factor 2-4)

Out of the multitude of investigated parameters only some are discribed in the following.

More or less intensive soil tillage has strong influence on various properties of the soil. Although the bulk density increases after long-term application of no-tillage (fig. 2) the soil structure is improved. For instance, increased biological activity leads to a pore system with high continuity of vertically pores (earth worm tubes, roots), which are not disturbed by tillage operation anymore. In the absence of a plough pan the penetration resistance course of the no-tillage variant shows a homogeneous transition between upper and lower soil layers.

The changed physical, chemical, and biological soil properties affect the aggregate stability and the fate of xenobiotica.

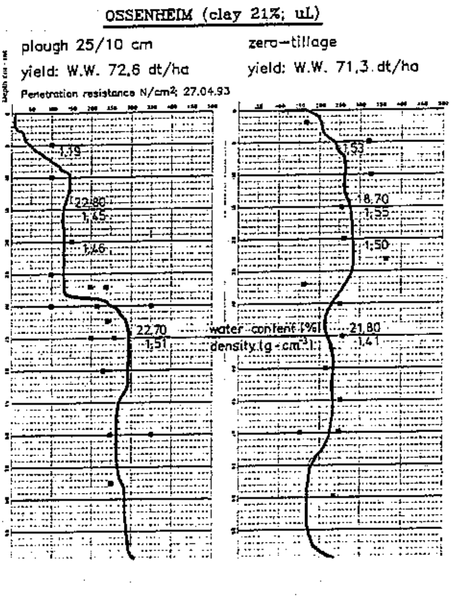


Figure 2: Penetration resistance and bulk density on a silty loam of plough and no-tillage.

In spite of the diverse advantages of no-tillage some disadvantages must be mentioned. For example, high amounts of straw residues at the soil surface can lead to problems during the seed placement. That's why straw management is very important in cereal crop rotations.

Aggregate stability and surface sealing

In order to assess the susceptibility of the different tillage variants to surface sealing the saturated hydraulic conductivity of the surface was measured directly after sowing and furthermore on several times during the vegetation period. For that purpose about 150 sampling cylinders/variant were pushed into the soil (0-5 cm) directly after sowing ensuring the surface of the sample was exposed to the natural rainfall. Depending on the intensity of precipitation events the cylinders were removed. The hydraulic conductivity was measured in the labaratory with the aid of a Haubenpermeameter after (2) following the technique of (3).

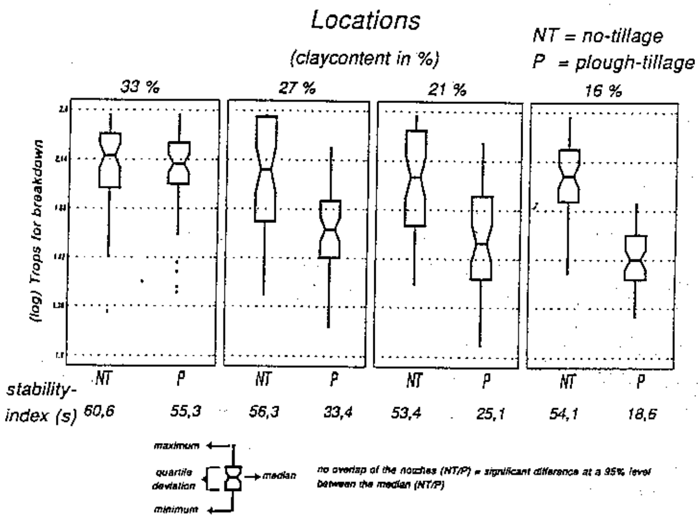


Figure 3: Aggregate stability after no-tillage and plough tillage on locations with different clay content.

In dependence of the registered rainfall a significant reduction of the hydraulic conductivity for the plough variant was measured (fig. 3). Due to the impact of raindrops on the bare soil a clear surface crust developed.

Contrary to the tillage variant, the no-tillage one did not show any sealing of the topsoil. A high amount of biogen macropores which are very functional and the protection of soil surface by a mulch layer lead to constant conductivity levels measured on this variant.

To determine the aggregate stability a single drop rainfall simulation with ovendried aggregates (40°C) was carried out . The usage of the measurement arrangement and the formula for calculation of the stability index (s) are descriped in (4).

On all locations the no-tillage variant showed a higher aggregate stability in comparison to the plough variant (fig. 4). The difference between both tillage systems decreased with increasing clay content. At last on the location with 33% clay content no statistically significant differences were obtained. In general, lower aggregate stability going along with decreasing clay content could be observed.

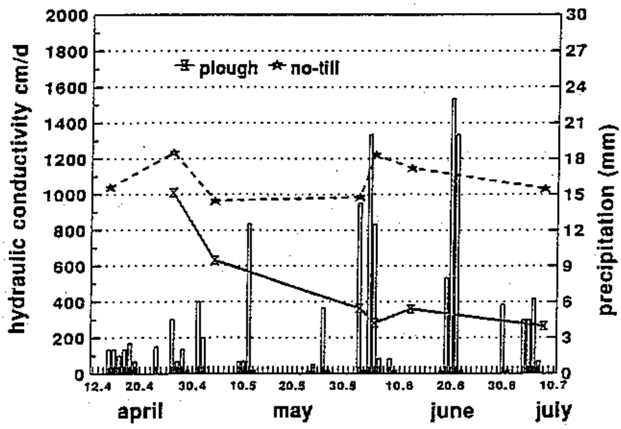


Figure 4: Dynamics of the saturated hydraulic conductivity on a loamy sand after sowing sugar beet (no-tillage/ plough tillage)

Fate of isoproturon in the soil

The long-term tillage project, conducted since 1979, provides a promising approach towards the aim of assessing the fate of soil herbicides under distinct ecological conditions. As a case in point, the behaviour of the herbicide isoproturon was investigated under natural conditions at the field site Ossenheim dúring the years of 1991-1993. Different soil tillage variants were compared. In the following, we focus on the behaviour of isoproturon in the upper 5 cm of the top soil within the variants no-till and conventional plough tillage, respectively.

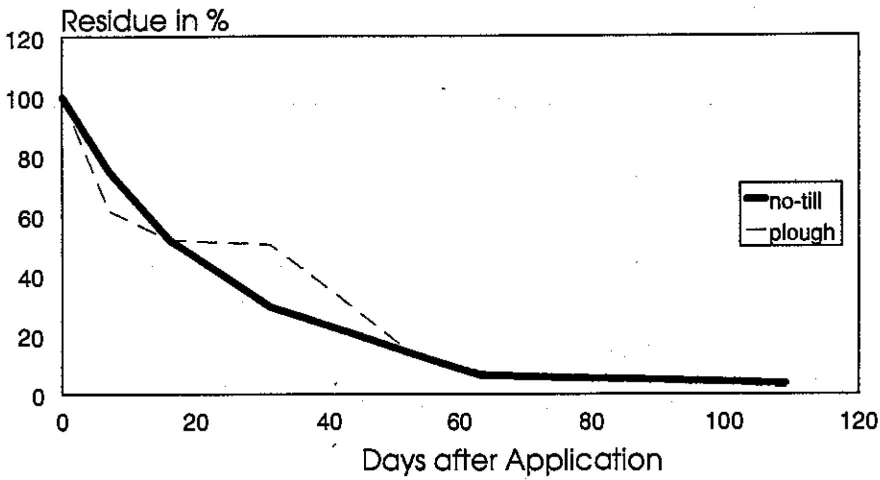


Figure 5: Dissipation of isoproturon, field site Ossenheim, 1991. Soil depth 0-5 cm.

The field site conditions with low precipitations and high sorption capacity of the soil diminished the chance for translocation of the herbicide into deeper soil layers. Thus, we may consider the dissipation of isoproturon mainly as a function of microbial degradation.

Fig.5 depicts the cometabolic degradation under both tillage variants no-till and conventional plough tillage in 1991. For easier comparability the initial herbicide concentrations were standardized to 100%.

In 1991, the first order degradation kinetics were approximated to their best fit. Thus, we may determine the persistence of this herbicide graphically or, alternatively, arithmetically. Tab. 1 shows the calculated DT-values which indicate persistence of the active substance. DT-50 is marking the time at which 50% of the initial concentration is no longer detectable. The same applies to DT-90.

Table 1: Calculated DT-values (in days) for isoproturon, R^2 as degree of approximation

Tillage system	DT-50	DT-90	R^2
Conventional tillage	20	70	0.951
No-till	18.5	59	0.999

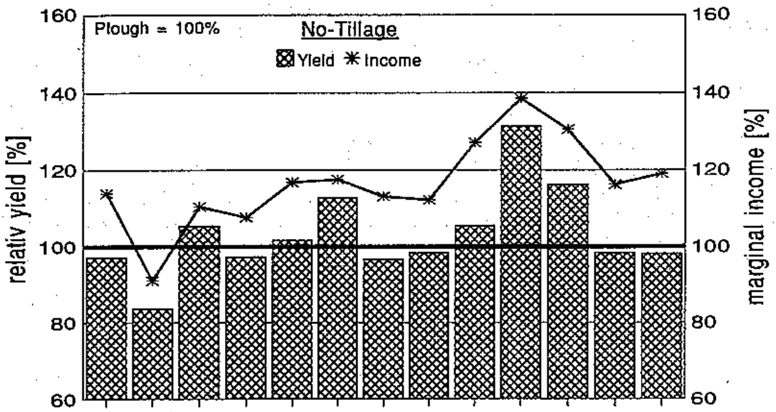
Particularly the obtained DT-90-values point out a slightly accelerated degradation in case of the no-tillage system when compared to the conventional ploughing method. Another hypothesis for faster dissipation should be an increased adsorption to the humic soil matrix. In this case, considerable amounts of the herbicide are fixed very strongly to the accumulated organic substance in the upper layer of the no-till variant. This results in, on one hand, decreased availibility for microorganisms and thus decreased degradation, on the other hand in reduced recovery within our chemical residue analysis.

If one assumes that the dissipation of herbicides is mainly caused by the activity of microorganisms in the soil (5), the results are not astonishing. In case of the no-till variant there was increased microbial activity in the top layer of the soil with a high level of humic substances (6). Studies conducted within this interdisciplinary research project revealed that the variant not turning over the soil prove to be more stable with regard to the toxic effects of the herbicides on the microflora and in comparison to the ploughing system (7).
The repetition of the field trial in 1992 showed, slightly modified, the same tendencies for the fate of isoproturon in the soil.

Yields and costs

Beside it's positive ecological effects no-tillage has decisive economical advantages compared to plough tillage. Simultaneously the same yield levels can be reached in absooute terms dependence of the soil type. The long-term soil tillage researches in Giessen (8) and also investigations in other European countries (9, 10, 11, 12) verify this.
Figure 6 shows the yields and the income of no-tillage in relation to the plough variant on a chernozem-brown earth of loess (silty loam). In a crop rotation over 13 years nearly the same yields of winter cereals were measured after no-tillage than after plough tillage. Increased yields (16,5 %) of sugar beets were harvested at that location using no-tillage.

A calculation of costs amounts up to 4-times lower production costs when no-tillage is carried out instead of plough tillage. That means in view of the actual market price a higher marginal income of 16 % within the demonstrated crop rotation.



Year	1981	'82	'83	'84	'85	'86	'87	'88	'89	'90	'91	'92	'93
Crop	WW	WW	SB	WW	WG	SB	WW	WW	WW	SB	WW	WW	WW
Yield P=plough [dt/ha]	42,2	67,6	667	69,4	60,7	778	53,7	62,8	55	665	86	68,3	72,6
Market price [DM/dt]	50	50	10	45	40	10	40	40	35	10	35	30	25

Figure 6: Relative yield [%] and income [%] of no-tillage compared to conventional plough tillage (Plough = 100%) at a silty loam (chernozem-brown earth).

Straw management

For the seed placement in an undisturbed (unloosened) soil structure special no-till drills are used. These machines are equipped with disc or hoe drill coulters.
In case of heavy straw residues both types of drill coulters have specific faults, especially if the straw is chopped and spread unsatisfactorily:

- the disc coulters push residues into the furrow without cutting them;
- the hoe coulters have the tendency to drag straw and plug the machine.

In comparative field trials the influence of suitable straw handling methods on seed placement, field emergence, and yields by direct sowing of winter wheat and winter rape have been investigated. Therefore 6 different straw handling methods are combined with the both direct sowing techniques, namely disc and hoe coulters.
In 1992/93, particularly winter rape reacts sensitively to straw in the seed bed. The field emergence and the plant density in the spring could be influenced in a positive way through specific straw management. Therefore higher field emergences were observed if direct sowing was carried out after a shallow stubble cultivation (in the narrow sense this is not an absolute no-tillage method) when compared to the method without additional straw handling.

Table 2: Influence of different straw-handling methods in combination with a Hoe Drill and a triple Disc Drill on field emergence, plant density in spring and yield of winter rape (field trial 1992/93).

NO-TILLAGE and Straw-Handling methods		Field emergence [plants/m^2] (rel. in %)	Plant density [plants/m^2] spring	Yield [dt/ha]	Thousand Seed Weight [g]
HOE DRILL	Field Chopper	61 (74,5)	44	52,1	4,9
	Stubble Cultivation	69 (84,5)	44	49,8	5,2
	Straw-Chopper	55 (67,2)	38	52,5	5,1
	Straw Gathering	57 (69,6)	32	47,9	5,1
	Combine-Low Cut	56 (68,3)	28	42,8	5,1
	Combine-High Cut	37 (45,5)	16	50,6	4,8
average		**56 (68,3)**	**33**	**49,3**	**5,0**
DISC DRILL	Field Chopper	55 (65,3)	30	43,1	4,7
	Stubble Cultivation	71 (84,8)	44	49,5	5,0
	Straw-Chopper	50 (59,3)	29	52,4	4,9
	Straw Gathering	62 (73,5)	32	52,6	4,6
	Combine-Low Cut	36 (42,3)	16	50,9	4,9
	Combine-High Cut	29 (34,8)	12	32,9	4,6
average		**52 (61,9)**	**28**	**47,6**	**4,8**

Table 2 shows a relative field emergence of winter rape of 84,6 % using the no-tillage system including a shallow stubble cultivation. Nearly 60 up to 75 % were obtained using no-tillage in combination with an additional straw chopping method. Particularly unfavourable effects on plant density of winter rape (field emergence between 35 and 46 %) caused direct sowing into high standing stubbles.

The rate of winter killing is very high, if the rape plants build long stems, which make the plants prone to frost damage or fungus disease. Slugs can also cause big damage, especially if straw gives them a cover. That's why sometimes considerable gaps of plant standings were found on plots with no-tillage after a combine-high cut.

In tendency field emergence was lower and rate of winter killing was higher by direct sowing through a disc drill than a hoe drill.

The determination of rape yield produced no statistically significant differences between the various no-tillage and straw handling methods. A reason for this could be the rape's high potential to compensate gaps of plant standing through branching. In the average of all variants yields of 48,5 dt/ha were obtained. The lowest yield was observed on plots with the triple disc drill after a combine-high cut. A positive effect on the rape yield could be found again if no-tillage was carried out after a shallow stubble cultivation or after the additional use of a straw chopper.

Similar observations were made by direct sowing of winter wheat, but winter wheat reacts not as sensitively to straw as rape. Although long unchopped stubbles have also more negative than positive effects, under certain circumstances direct sowing of winter wheat without any additional straw handling is possible.

CONCLUSION

No-tillage systems provide several advantages, some of them are presented in this manuscript: Due to changed soil properties we found a higher aggregate stability and lower tendency towards soil sealing.
Increased microbial activity and larger amounts of organic matter in the top layer probably cause an accelerated dissipation of isoproturon in the soil.
With the aid of an additional straw handling method to no-tillage (straw chopping or shallow stubble cultivation) problems with straw residues can be diminished.

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EARLY SOWING - A WAY TO REDUCE COSTS, INCREASE YIELD AND IMPROVE SOIL STRUCTURE?

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ABSTRACT

Traditional seedbed preparation in Sweden includes 3-4 harrowings followed by sowing. Since the soil is normally at field capacity after winter, this system implies a major risk of soil compaction, and the farmer has to wait for the soil to dry before seedbed preparation can be started. Early sowing of spring cereals without harrowing is a technique that has been made possible by new types of sowing machines and improved tyre equipment. The method seems most suitable on self-mulching clay soils and light soils with single-grained structure. Early sowing was tested in 41 experiments in Sweden during 1988-93, resulting in increased yields, fewer tillage operations, and improved water uptake compared to conventional seedbed preparation. We think that this new technique could lead to reduced costs, high yields and improved soil structure. Lengthening of the growing period and an earlier barvest that faciliates autumn sowing will also result in early sowing having positive environmental effects by reducing N-leaching.

INTRODUCTION

Seedbed preparation for spring-sown crops has been a major research field in soil tillage in Sweden for more than 25 years. Some general problems are: The soil normally becomes water saturated during the winter or at snowmelt, and is very susceptible to compaction in the spring. The farmer then waits for the soil to become trafficable and friable, and by the time the springsown crops have developed into a fully transpiring stand, several weeks with good light and temperature conditions for crop growth have normally passed. The spring is often dry, which means that the crop cannot rely on precipitation for germination and growth, but must be able to use the soil moisture available at the time of sowing.

Conventional seedbed preparation, which has been supported by research results, includes 3-4 harrowings followed by sowing. The general features of the seedbed are shown in Fig. 1 a. Harrowing aims at levelling the surface and creating a 4-5 cm layer of fine aggregates for evaporation control. The seed is placed on a firm seedbed bottom, which is formed mainly by compaction caused by the harrowing tractor. The method is not really suitable for heavy clay soils because: 1. These soils are self-mulching, which means that small aggregates giving protection from evaporation are created by frost. This diminishes the need for harrowing. 2. Since a fine layer is formed naturally, the central part of the topsoil dries very slowly, making the soil especially susceptible to compaction when normal seedbed preparation is carried out.

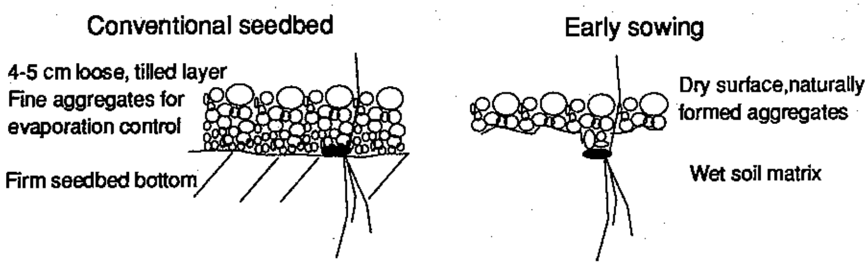


Fig 1. a) Traditional Swedish seedbed for springsown crops. b) "Early sowing" seedbed.

One way to partly solve the problems outlined above, may be to sow very early without any other tillage in spring, Fig 1b. In the present context "early sowing" is considered to be a system where the soil is tilled and levelled in the autumn, and sowed in spring without harrowing 1-6 weeks earlier than the normal time for seedbed preparation, which is possibly followed by 1 harrowing to create an evaporative barrier and to control weeds. This method has been made possible mainly by improved tyre equipment and new seed coulters that do not need a firm seedbed bottom to place the seed at the desired depth.

Early sowing also prolongs the growing period for spring-sown crops and enhances the possibility of sowing winter cereals. These factors could lead to a more efficient water uptake and reduced leaching.

The method of early sowing without harrowing was studied in a total of 41 field experiments during 1988-1993. The main purpose was to study effects on yield and plant establishment, but also to study possible effects on soil structure and the environment.

MATERIAL AND METHODS

The effects of early sowing have been studied in field experiments since 1988. The major part, early sowing on clay and till soils, included three treatments:

A = conventional seedbed preparation and sowing
B = sowing without harrowing 1-2 weeks before normal sowing time
C = sowing as early as possible

The fields were levelled by harrowing in the autumn after mouldboard ploughing. In some experiments, the interaction between sowing time and other factors, i.e. primary tillage (mouldboard ploughing versus ploughless tillage), crop type, crop variety and seed coulter, was studied.
Main emphasis was on studying yield and plant establishment, but studies were also made of penetration resistance, water uptake and effects on weeds. Maximum rooting depth was measured in 7 experiments in 1992 and changes in water content during the growing period were studied in one experiment in 1993 using time domain reflectrometry. Soil penetration resistance was measured with a penetrometer in several of the experiments.

Early sowing was also tested on light sandy soils in southern Sweden. Four of the treatments were:

A = autumn ploughing, conventional seedbed prep., fertilizer broadcast
B = autumn ploughing, early sowing in one pass with PTO-driven harrow combined with fertilizer placement
C = spring ploughing, conventional seedbed prep., fertilizer broadcast
D = spring ploughing, early sowing in one pass with PTO-driven harrow combined with fertilizer placement

Ten experiments were conducted in 1988-93. The sowing was generally carried out 1-2 weeks earlier in B and D than in A and C (in 1992 six weeks earlier).

RESULTS AND DISCUSSION

Yield and plant establishment

Clay and till soils

Relative yield (A=100) as a function of difference in sowing time between sowing without harrowing and conventional sowing time is shown in Fig. 2. The early sowing caused a significant increase or decrease in yield compared with conventional sowing in most of the individual experiments, but on average the differences between treatments were small. When sowing without harrowing was carried out at the same time as the conventional seedbed preparation, the yield decreased by 4 %, whereas sowing more than 20 days before normal sowing time on average gave a 4 % increase in yield. This indicates that sowing without harrowing mainly should be carried out very early in the spring. If this cannot be done, the conventional seedbed preparation gives the highest yield.

Plant establishment was generally somewhat poorer in early-sown treatments, on average 8 % fewer plants than with conventional seedbed preparation. In many cases, the early sowing gave

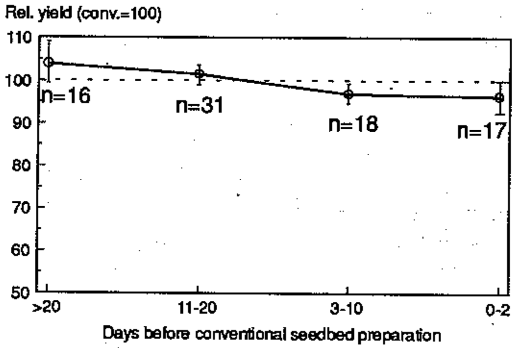


Fig 2. Relative yield with early sowing (conventional=100) as a function of difference in sowing time. Error bars show standard error of the mean.

higher yield than conventional seedbed preparation, even when the number of plants was lower. The coefficient of determination for relative yield as a function of the relative number of plants in the early sown treatments (conventional sowing=100) was only 0.03. This means that other factors than plant establishment had a bigger influence on yield. The most important factor seems to be the type of weather during the growing period. A dry spring followed by a rainy summer generally caused lower yield in the early-sown treatments, probably because the crop is most sensitive to drought in the early vegetative phase. The early-sown crop had then developed further when the rain started, and suffered more from drought. If the drought continued throughout the growing period, or there was a more uniform rainfall distribution, the early sowing usually gave higher yields. Other reasons for lower yield after early sowing are the risks of frost, crust formation or denitrification if there is a rainy period after sowing.

Barley, oats and spring wheat were compared in four experiments in 1991 and 1992. There was no significant interaction between crop and sowing time.

Sandy soils

Early sowing on light sandy soils gave higher yield than conventional seedbed preparation in nine out of ten trials in southern Sweden. As an average of six years, the increase was about 20 % (Fig. 3).

Conventional sowing was always combined with broadcast fertilizer, whereas the fertilizer was placed in the early-sown treatments. This makes it impossible to separate the effects of fertilizer placement and sowing time on yield.

Root development, water uptake and penetration resistance

The results of the studies of root development in 1992 are shown in Fig. 4. Clear differences between treatments occurred only in 2 experiments, in the other cases the rooting depth was approximately the same for early and normal sowing. However, the water content at maximum rooting depth was on average 4.7 % (w/w) lower in the early-sown plots ($p<0.05$). In all but one of these experiments (no. 5), the yield was higher following early sowing.

Figure 3. Relative yield in 10 experiments on sandy soils. The fertilizer was broadcast in the conventionally-sown treatments and placed in the early-sown treatments.

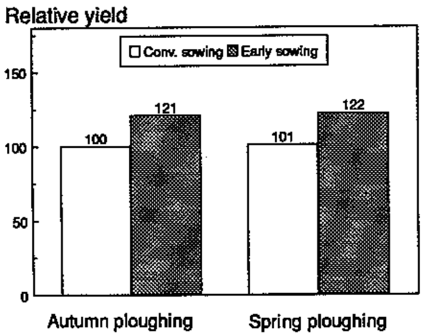
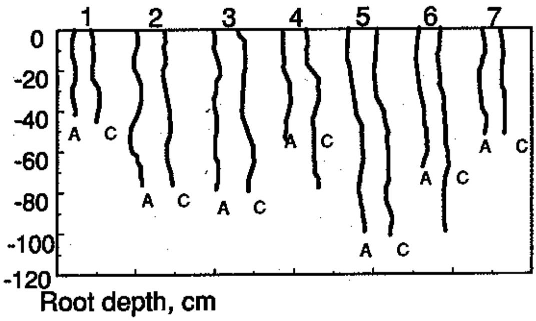


Figure 4. Root depth in 7 experiments with early (C) compared with conventional sowing (A). Sowing date in A and C and date of root depth measurement (R) :

1. A=12/4, C=1/4, R=4/6.
2. A=12/4, C=10/3, R=4/6.
3. A=23/4, C=27/3, R=5/6.
4. A=11/5, C=27/3, R=9/6.
5. A=13/5, C=12/4, R=15/6.
6. A=12/5, C=1/4, R=22/6.
7. A=12/5, C=1/4, R=22/6.



The changes in water content at 20 cm depth in one experiment at Uppsala in 1993 are shown in Fig 5. Plant water uptake started earlier in the early-sown treatment, which led to a faster decline in soil water content. The same pattern was repeated at 40 cm depth. The water content at 80 cm depth was also studied, and did not change during the growing period in any of the treatments. In this experiment, the early-sown plots suffered more from drought in the spring, which caused decreased tillering and 29 % less yield than the conventional treatment.

In comparison with conventionally-sown treatments, penetration resistance of the soil was both lower and higher in early-sown treatments (Arvidsson & Rydberǵ, 1993). Since the soil water content is often different between the treatments, penetrometer measurements is not a very useful method to study soil strength in these experiments.

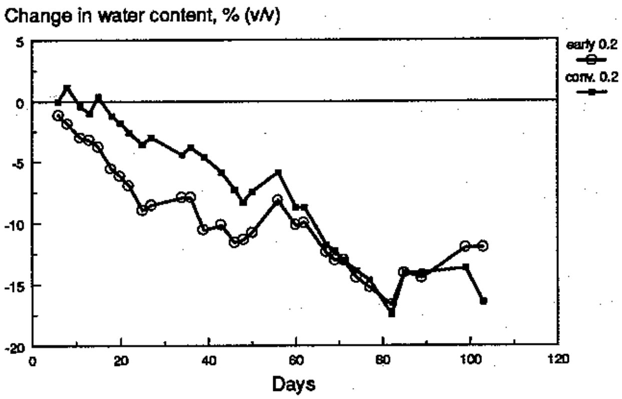


Fig. 5. Changes in water content at 0.2 m depth for conventional and early sowing during the growing period in one experiment at Ultuna in 1993. The conventional treatment was sown on day 4, 20 days after the early-sown treatment.

CONCLUSIONS

Early sowing without harrowing is a very promising method of increasing the length of the growing period and increasing yield of spring-sown crops. The method seems most suitable on self-mulching clay soils and light soils with single-grained structure. Some important facts to consider when using this method are:

- Plant establishment is generally somewhat poorer than with conventional methods. There is also a risk for crust formation since the time between sowing and emergence is very long.

-Fertilizer placement at the time of sowing might lead to denitrification if there is a wet period after sowing. This probably occured in at least one experiment in 1992.

-It is very important to avoid soil compaction and ruts while sowing. In the experiments presented here, tyre inflation pressure was normally 50 kPa and in some cases even lower.

-If the weather is dry in spring and early summer, and wet later in the summer, the early sowing might be a disadvantage since the plants have developed further and suffer more during the later part of the dry period. This is probably what happened in some of the experiments with low yields in 1992 and 1993.

As a conclusion of the experiments so far, we think this tillage system could have the following effects:

1. Lowering of costs: Rydberg (1991) demonstrated that early sowing in combination with ploughless tillage may reduce total costs with 850 SEK/ha (100 US $/ha).

2. High yield: The yield in field experiments has been higher than with conventional tillage.

3. Improvement in soil structure: Less traffic reduces soil compaction.

4. Positive environmental effects: Early sowing may increase yield which increases the uptake of nutrients. Longer growing period increases water uptake, and earlier harvest faciliates sowing of winter cereals. All these factors should reduce nutrient leachage and erosion.

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DEVELOPING OF A NEW CROPPING SYSTEM FOR SUGAR BEET PRODUCTION RELATED TO PROTECTION OF THE ENVIRONMENT

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ABSTRACT

This study is concerned with developing new cropping practices which reduce mechanization costs and ensure the conservation of soil fertility while maintaining production. The study was performed in the sandy-loamy region of Belgium. We tested direct-drilling of sugar beet in an intercropping used as cover crop (mulch seeding technique). With this soil tillage technique, soil loosening and seed-bed preparation took place in early September after cereal harvesting. Different tools were tested and compared with the conventional practice of tbe region. Nitrogen dressing was also taken into account. Several measurements were made: assessment of the emergence, soil nitrogen content, sugar content and sugar yields. The study has highlighted the advantages of tine cultivators used in the mulch seeding technique: better and more regular emergences, reduction of sealing, crusting and erosion, equivalent sugar yields.

INTRODUCTION

In Western Europe, the well-known environmental deterioration processes caused by intensive cropping systems (compaction, erosion, loss of humus, pollution, ...) together with the economical context and the need to reduce production costs have led farmers to try other cultivation metbods than conventional mouldboard ploughing. Simplified cultivation systems, ranging from no-tillage to direct-drilling bave often been considered viable alternatives (1 and 2). However, previous studies showed that for sugar beet, such tillage techniques can involve yield losses in loamy and sandy-loamy soils (3 and 4). In North-West Europe, a new cropping technique for row crops (5) is actually the subject of numerous research: the under-sowing cultivation (also called mulch seeding) which consists of planting the row crop directly without any soil tillage in a vegetable mulch created by an intercropping or by crop residues.

At Gembloux (Belgium), very simple experiments investigating mulch seeding techniques for sugar beet were started in September 1990, the aim being to compare two September soil preparations (ploughing and tine cultivation) combined with two ground protections (with or without white mustard sowed as cover crop). The results of trials (6), have clearly shown the effectiveness of mulch (straws + mustard) in limiting nitrate leaching to the groundwater and in preventing crust formation. They have also shown that sugar beet emergences were more regular and more complete when an intercropping was sowed, especially in ploughed plots. Unfortunately the advantages of the mulch seeding technique could not be assessed because the traditional practice of that region was not included. This paper takes new trials into account in which different tillage treatments are tested and compared to the traditional system (winter ploughing). Field emergence, sugar content and yields are presented and discussed.

MATERIALS AND METHODS

This study was conducted on a sandy-loamy soil in the vicinity of the "Station de Phytotechnie" (Gembloux - Belgium). Six trials were set up in three sites (Table 1) after the harvesting of winter wheat (Triticum aestivum L.) and straw manuring. White mustard (Sinapis alba L.), a frost sensitive and easy to grow cover crop, was established as intercropping. For sugar beet, the variety Cyrano was drilled at the density of 135000 seeds per hectare with the same special spacing drill.

In each trial, a split-plot experimental design with three replications was adopted. Five soil tillage systems were randomly allotted to the main plots. These large-size (10 m x 150 m) plots were subdivised among four sub-plots receiving different amounts of fertilizer N.

Table 1 Data on trials.

Year	1991/1992			1992/1993		
Trial	Grez92(1)	Court92	Chastre92	Grez93	Court93	Chastre93
Soil tillage + mustard sowing	09/09/91	10/09/91	10/09/91	09/09/92	09/09/92	09/09/92
Seed density for mustard	10 kg/ha	11 kg/ha	15 kg/ha	12 kg/ha	15 kg/ha	15 kg/ha
N-manuring for mustard	80 kg/ha	80 kg/ha	30 kg/ha(2)	0 kg/ha(3)	80 kg/ha	60 kg/ha
Winter ploughing (4)	15/12/91	20/12/91	20/12/91	28/12/92	11/01/93	11/01/93
Sugar beet sowing	07/04/92	10/03/92	10/04/92	23/03/93	16/03/93	19/03/93
Sugar beet harvest	22/10/92	16/10/92	31/10/92	29/09/93	30/09/93	28/09/93

(1) In this trial, plots with traditional system (TS) were sowed 4 days later than the others (11/04/92) because the soil was too wet to be satisfactorily worked and drilled at this moment. (2) Spreading of 8 t/ha of poultry manure on straws. (3) Spreading of 12 t/ha of poultry manure on straws. (4) Only in the traditional system.

Soil tillage treatments

The two cropping systems experimented are described in Table 2.

Table 2 Cropping system experimented.

	Traditional System	Mulch Seeding
Autumn	*Shallow cultivation* *Sowing of mustard*	*Soil loosening* *Seed-bed preparation (Rotary harrow)* *Sowing of mustard*
Winter	*Mouldboard ploughing (25 cm)*	*Herbicide spraying (Glyphosate)*
Spring	*Seed-bed preparation* *Sowing of sugar beet*	*Direct-drilling of sugar beet*

The five soil tillage treatments are: A) Traditional ploughing System (TS); B) Mulch Seeding with mouldboard **plough** used as soil loosener (MSplou); C) Mulch Seeding with a vertical **spad**ing machine used as soil loosener (MSspad); D) Mulch Seeding with **sub**soiler (curved tines) used as soil loosener (MSsub1); E) Mulch Seeding with subsoiler (straight tines) used as soil loosener (MSsub2).

Nitrogen treatments
Nitrogen application took place a few days after sowing. Four amounts of nitrogen fertiliser were tested (Table 3) in order to take this factor into account while interpreting the results if a possible interaction between soil tillage and N-fertilisation were to occur.

Table 3 Nitrogen amounts tested (kg N/ha).

	Grez92	Court92	Chastre92	Grez93	Court93	Chastre93
N1	0	0	0	0	0	0
N2	60	75	65	70	70	70
N3	120	150	130	140	140	140
N4	150	180	160	180	180	180

RESULTS AND DISCUSSION

Emergence
Plant counts were made about two months after the sowing of sugar beet. The prevailing climatic conditions (rainfalls) during the emergence period (about one month after the sowing date) and the populations observed are summarised in Table 4. The Grez92 trial is not considered here because plots managed with the traditional system were sowed four days after the others; soil moisture content and weather conditions were different. Crop establishment was positively affected.

From Table 4 it appears that, whatever the soil tillage system, the mulch seeding technique is better compared to the traditional system when tbe climatic conditions are bad (Court92 and Chastre92). Mustard protects the soil during the whole intercropping and maintains the arable layer and the soil surface in a porous and permeable status. The direct-drilling technique allows this favourable structure to be preserved so that after sugar beet sowing the soil surface is less sensitive to crusting than in freshly tilled plots. Wheat straw mulch still improves this effect in very heavy sealing and crusting situations (Court92); the best stands were obtained with the subsoiler 2 (straight tines) which allowed the greatest quantity of straw to remain on the top. These results and visual observations confirm the previous conclusions and those of other authors (7 and 8) underlining the interest of the under-sowing technique to avoid erosion risks in sugar beet.

When the emergence conditions are good or very good (Court93 and Chastre93), all the experimented systems lead to a very dense population (>100000 plants/ha). The significantly worse emergences obtained in the Chastre93 trial and in dry conditions (Grez93) can be ascribed to a technical detail: when straws at the soil surface are very abundant, it is difficult to create good contact hetween seed and soil. Despite this fact, stands were sufficiently abundant. Other authors (9) using a classical spacing drill have obtained a 10 to 15 % decrease in beet stands when compared to conventional winter ploughing. However, these authors report that even in these cases, sugar yields were equal or even higher.

Table 4 Rainfalls (mm) during the emergence period and populations observed (1000 plants/ha). Values followed by the same letter are not signficantly different ($\alpha = 0.05$).

	Court92	Chastre92	Grez93	Court93	Chastre93
Sowing date (J day)	10/03/92	10/04/92	23/03/93	16/03/93	19/03/93
		Rainfalls (mm)			
From J+1 to J+10	48.1 (1)	28.9 (2)	5.0	1.2	1.2
From J+11 to J+20	32.5	30.6	11.0 (3)	14.1	18.8
From J+21 to J+30	11.6	24.8	7.5	14.2	9.8
Total (mm)	92.2	82.3	23.5	29.5	29.8
Visual observations	*crusting*	*erosion*	*too dry soil*	-	-
		Population/ha (x 1000)			
TS	87 b	94 b	107 a	113 a	122 a
MSplou	91 ab	105 a	109 a	114 a	120 a
MSspad	91 ab	107 a	109 a	116 a	119 ab
MSsub1	92 ab	105 a	101 b	114 a	121 a
MSsub2	95 a	108 a	102 b	116 a	116 b

(1) Two very rainy days with 18.0 and 14.6 mm involving sealing and crusting (nearly level soil). (2) One day with 11.4 mm involving severe erosion in the TS plots (sloping land). (3) One day with an important rainstorm (9.0 mm) almost totally lost by surface runoff (dry soil and sloping land).

Sugar content

Sugar contents always decreased with increased amounts of N-fertiliser. For soil tillage treatments, sugar contents measured at the harvest are given in Table 5.

Table 5 Sugar contents. Not significant: n.s.

		Grez92	Court92	Chastre92	Grez93	Court93	Chastre93
Soil tillage	TS	16.6	16.4	16.1	17.1	18.2	16.7
	MSplou	17.0	16.4	16.6	17.0	18.0	17.0
	MSspad	16.7	16.2	16.3	16.7	17.9	16.7
	MSsub1	16.8	16.3	16.4	17.1	18.0	16.9
	MSsub2	16.5	16.5	16.7	16.7	17.9	16.5
	LSD 0.95	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*
Interaction Soil tillage x N		*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*

From Table 5 it appears that soil tillage treatment has no effect on sugar content, confirming conclusions obtained by others (10).

Root yield

From Table 6 it appears that no interaction between soil tillage and N- fertilisation could be displayed. For this reason soil tillage treatments are compared through the 4 N-doses mean.

Differences between soil tillage systems are low except in two trials (Grez92 and Court93) where the findings are the opposite. Consequently, if we consider the six experiments, we cannot say that one treatment is better than the others. However, in mulch seeding techniques, the subsoiler 2 seems to be preferred to mouldboard plough even if differences are not as important as those previously measured (6).

Table 6 Root yields (t/ha). Not significant: n.s.

		Grez92	Court92	Chastre92	Grez93	Court93	Chastre93
Soil tillage	TS	70.7	71.9	79.0	58.8	78.4	67.5
	MSplou	73.6	69.5	77.7	58.3	74.2	67.4
	MSspad	76.0	69.7	77.3	58.7	76.2	68.1
	MSsub1	74.2	72.8	78.9	56.5	75.8	66.1
	MSsub2	75.4	71.8	78.8	59.6	75.0	69.2
	LSD 0.95	*3.9*	*n.s.*	*n.s.*	*n.s.*	*3.0*	*n.s.*
Interaction Soil tillage x N		*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*

Sugar yield
Sugar yields are presented in Table 7.

Table 7 Sugar yields (t/ha). Not significant: n.s.

		Grez92	Court92	Chastre92	Grez93	Court93	Chastre93
Soil tillage	TS	11.7	11.8	12.7	10.0	14.2	11.3
	MSplou	12.5	11.4	12.9	9.9	13.3	11.5
	MSspad	12.7	11.3	12.6	9.8	13.6	11.4
	MSsub1	12.5	11.8	12.9	9.7	13.6	11.2
	MSsub2	12.4	11.8	13.2	10.0	13.5	11.4
	LSD 0.95	*0.4*	*n.s.*	*n.s.*	*n.s.*	*0.7*	*n.s.*
Interaction Soil tillage x N		*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*
N-fertilsation							
	N-opt (1)	69	85	0	93	94	84
	Y-max (2)	12.6	11.8	13.6	10.4	13.9	11.7
	r^2 (3)	*0.96*	*0.40*	-	*0.99*	*0.90*	*0.99*

(1) N-opt = Optimal N-amount and (2) Y-max = maximum yield calculated by the regression curve proposed by the ADAS (Agricultural Development and Advisory Service) which is of the following form: $Y = a + b N + c\ 0.99^N$ (a, b and c are parameters). (3) r^2 = determination coefficient.

The optimal N-amount and the maximum yield can be considered as the reflecting of the pedo-climatic conditions prevailing during the growing season. They were excellent in the Chastre92 trial and clearly less favourable in the Grez93 trial (small Y-max associated with high N-opt). Despite these very different pedo-climatic conditions, no interaction between soil tillage and N-fertilisation could be displayed. Owing to these results, no adaptation of Nitrogen manuring can be proposed as opposed to the conclusions expressed by (7).

CONCLUSION

From the findings presented here and results obtained previously or by other authors, it can be concluded that for a sugarbeet crop established after a cereal crop, the mulch seeding technique is a feasible crop farming technique which allows equivalent sugar yields to be achieved. White mustard can be recommended as cover crop because it withstands late-sowing date (which is generally the case when the preceding crop is winter wheat), is easily grown and destroyed and is efficient to reduce nitrate leaching to the groundwater. When the weather is good during the sugar beet emergence period, a slight negative effect on crop establishment can be noticed but without any incidence on yields. In rainy conditions, the complete coverage of the surface is beneficial to prevent crusting and erosion and to give good emergences. This effect is still improved when straws are chopped and mixed in the seed-bed. The subsoiler with straight tines which leaves the maximum of straw on the top can be used instead of the conventional mouldboard plough. This new cropping system (straw manuring + ploughless tillage + mulch seeding) can be recommended as viable conservation tillage.

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LESSONS FROM A 26-YEAR TILLAGE EXPERIMENT ON CEREALS

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ABSTRACT

A long-term tillage experiment was conducted from 1966 to 1992 on a loam soil in south-east Scotland. The crop was spring barley until 1983 and winter barley thereafter except for oil seed rape in 1989. Two long-term treatments (direct drilling and conventional mouldboard ploughing) were compared with two others which varied during the experiment but included broadcast sowing plus rotavation. Measurements were mainly of crop performance and soil physical conditions. The experiment revealed grass weed infestation, soil compaction damage, straw disposal and surface acidity as the main problems associated with non-ploughing systems for continuous cropping in a humid temperate climate. Coping with these problems required considerable management inputs which were limited by available work days. The ploughed treatment yielded slightly more than the others and required least management, though the surface soil structural stability, organic matter content and earthworm content were less than in the direct drilled (no-till) treatment. Non-ploughing systems might be applicable to rotational cropping under more extensive and sustainable farming systems than those used at present. The experiment suffered towards the end because of deterioration of site drainage and decreased scientific input, but it proved useful for complementary experimental studies.

INTRODUCTION

At the beginning of the experiment, initiated by the East of Scotland College of Agriculture and the Scottish Institute of Agricultural Engineering in 1966, both direct drilling (no-till) and continuous barley growing were regarded as novel ventures with considerable promise. Thus the original objective of the experiment was 'to examine the different physical states of the soil produced by different tillage treatments and relate these to root growth and crop yield in the short and the long term for a continuous long-term barley monoculture system'. The experiment is currently suspended under grass. Here we examine how the experimental objectives and measurements changed over the years and what we can conclude both from the results gathered and from the conduct of the experiment.

MATERIALS AND METHODS

Site

The experimental site is about 10 km south of Edinburgh at an altitude of 170 m. Half of the replicates was located mainly on a eutric Cambisol and the other half was located mainly on a

Gleysol. The texture of the topsoils is predominantly loam with 15-18 % clay. The subsoils are imperfectly (Cambisol) or poorly (Gleysol) drained. The site is in the humid temperate climatic zone, with an annual rainfall of about 900 mm. The limitations to crop productivity are soil wetness, unfavourable structure and texture and variable weather. Further details of the site and soil properties were given in (1).

Experimental design and tillage treatments

The tillage treatments were applied to main plots of dimension 12 m x 48 m and four nitrogen treatments (different rates) were applied to sub-plots (6 m x 24 m). There were eight replicates, to give a total of 32 main plots and 128 sub-plots. The original tillage treatments and crop types and subsequent alterations are summarised in Fig. 1. The chisel plough and the deep mouldboard ploughing treatments (reported in 2 and 3) are not considered here. The first two seasons of the experiment (1966-67) were used for tests of site uniformity. Unlike most direct drilling experiments in the U.K., the straw was not burnt before the tillage treatments were applied, but was harvested for animal use as is conventional in the locality.

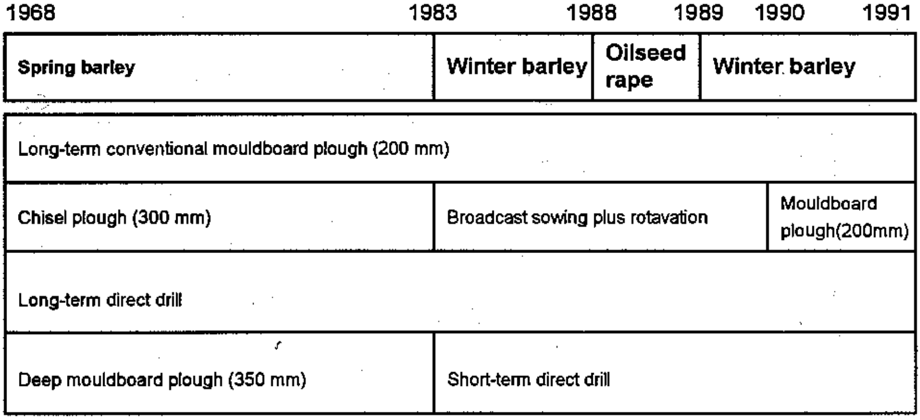

Fig. 1. Sequence of cropping and tillage treatments through the experiment.

Winter barley was substituted for spring barley in 1983 because it was thought less susceptible to unfavourable seedbed conditions and to benefit more from the timely sowing associated with non-ploughing systems. At the same time, a new (short-term) direct-drilled treatment and a reduced tillage treatment in which seed were broadcast were introduced. Also the nitrogen treatments were replaced by combinations of two autumn and two spring nitrogen treatments.

RESULTS AND DISCUSSION

Soil suitability for non-ploughing

Direct drilling gave grain yields (Fig. 2A) which were often lower than those from conventional ploughing. Reasons for this in the early spring barley years, were difficulty of control of the grass weed *Agropyron repens* (couch grass), the development of surface acidity and adverse soil physical conditions under direct drilling. The first two problems were eventually overcome by appropriate amendments. However, the adverse soil physical conditions such as unfavourable seedbed conditions, poor soil aeration and high soil strength which resulted in slower root growth (2) were less easy to control and influenced grain yield on the Gleysol more than on the Cambisol (Fig. 2B). These factors were considered to limit the suitability of the Gleysol for direct drilling spring cereals (3). The change from spring to winter barley caused a sharp increase in overall yield averaged over seasons from 4.18 t/ha to 6.27 t/ha and virtually eliminated any consistent difference associated with soil type.

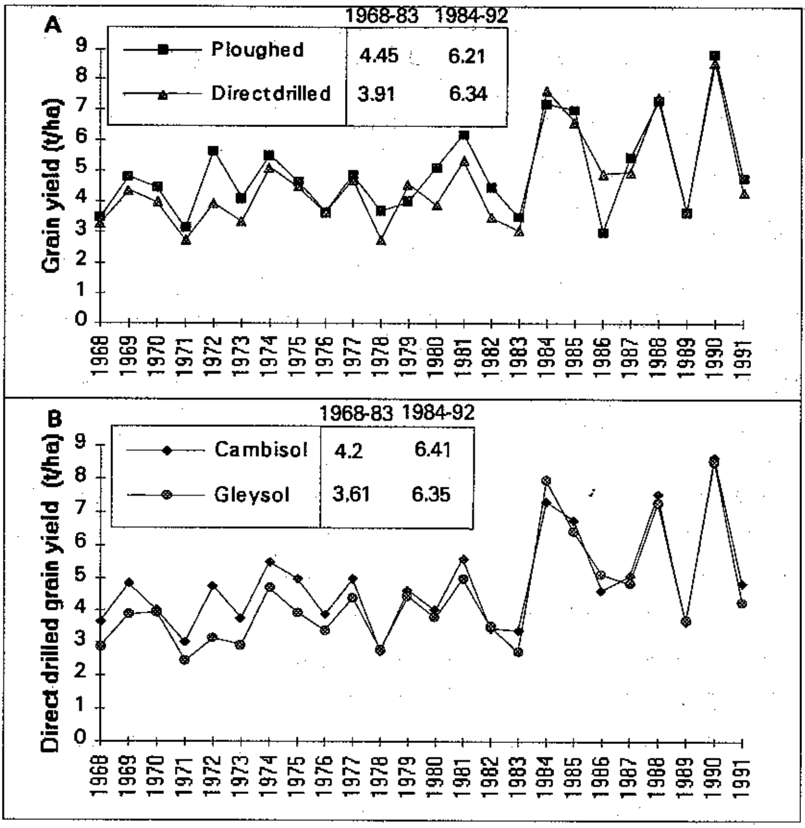

Fig. 2. Grain yields at or near the recommended nitrogen level under long-term ploughing or direct drilling: spring barley, 1968-1983; winter barley, 1984-1991 except for 1989 which was oil seed rape. The mean yields given in the boxes exclude oil seed rape.

Overall yields varied more between seasons under winter barley than under spring barley. Winter barley yields were lighter when there was a wet winter or spring, possibly because of losses of available soil nitrogen by denitrification (K. A. Smith, personal communication, 1992). In addition, the differences in yield between tillage treatments were considerably larger in the spring crop. This agrees with other long-term experiments involving winter cereals where straw is baled or burnt (4,5). Under direct drilling, spring barley was more constrained than winter barley by the soil physical conditions, possibly because the later growth of the root system encountered extra impedance. Localised areas of compact soil and poor drainage reduced winter barley yields, and, although means presented in Fig. 2 were adjusted, the effects of these areas are important.

Much greater management inputs were required to maintain the direct drilled yields comparable to those of ploughing. These inputs, which included raking of loose straw and the control of slugs, grass weeds and fungal infections, required additional workdays, which were limited by wet weather. In some seasons there were insufficient days: an infestation of soft brome (*Bromus mollis L.*) could only be controlled by using oil-seed rape as a break crop in 1989. Indeed, in the last year of the experiment (1992), the combination of a fungal infection in early spring and a soft brome infestation which could not be controlled by herbicides produced crop failure on sufficient direct drilled plots to make an overall assessment of yield impossible. Accordingly, direct drilling under intensive, continuous cereal production was deemed unsuitable at this site but the seed broadcasting and reduced tillage system used in a crop rotation was considered more suitable since it coped rather better with straw residues, surface compaction and weeds than did direct drilling (7)..

Experimental design and conduct

The experimental design, where numbers of treatments, plots and subplots are powers of two, was satisfactory and allowed re-allocation when the treatments were changed. Covariate analysis was used to adjust crop yields in plots containing badly drained areas. Crop growth on these plots was affected adversely not only by the excessive wetness, but also by enhanced grass weed populations. These effects were worst in wet seasons (e.g. 1989, see (7)) and tended to increase through the experimental period as the drainage in some plots, particularly those under direct drilling, progressively deteriorated.

Adherence to the original experimental objective varied according to changes in staff and their commitment but was broadly satisfactory though no root growth measurements were made after 1983. A more strictly defined protocol and procedure for updating that protocol when necessary would have been desirable. Towards the end, the experiment was running on little more than a 'care and maintenance' basis. Many soil physical measurements were made (1, 3, 7, 8): some proved to be of minor relevance to crop growth, particularly in the winter barley period but others (e.g. bulk density and organic matter) provided useful monitoring information. Inconsistencies in depth and type of measurement make the assessment of long-term trends difficult - for example, organic matter was assessed using four different methods. The thorough characterisation of soil and site properties made it a very useful 'test bed' for assessing new measurement techniques (e.g. (6)) or for making investigations of factors complementary to those measured regularly e.g. soil denitrification (9) or soil temperature (10). In this respect the split of the experiment over two main soil types proved remarkably useful. Indeed, the fencing and plot markers of the experiment have been preserved so that the site can be re-used as required.

Environmental aspects

During the experiment the emphasis of farming changed from maximal to sustainable crop production with increasing interest in environmental protection. The original direct drilled and conventional ploughed treatments were retained throughout the experiment. The other two tillage treatments and the nitrogen treatments were adjusted according to current farmer interest. However these adjustments were relatively minor and tied closely to the interest of the farm advisory service. Opportunities for departure from other traditional farming practices could have been foreseen better by modifying treatments and by including more soil chemical and soil biological measurements. Nitrogen uptake by spring barley in the critical stages of early growth was less under direct drilling than under ploughing (2). Mineralisation of nitrogen over a period of seasons was also slower under direct drilling (2). Losses of nitrogen by denitrification were likely to be substantial at this site and to have been influenced by tillage (9) though measured emissions of nitrous oxide were small. Considerably greater earthworm (11) and beetle populations were found under direct drilling than under ploughing. Beetles were measured because they consume aphids which transmit cereal virus disease. Shallow tillage systems can give increased fixation of carbon (12) and this appears to have happened here with organic matter accumulating under long-term direct drilling (Fig. 3). In comparison to ploughed soil, this organic matter also contained a greater proportion of hot water soluble carbohydrates, probably of microbial origin, and involved in stabilizing soil aggregates (Fig. 3).

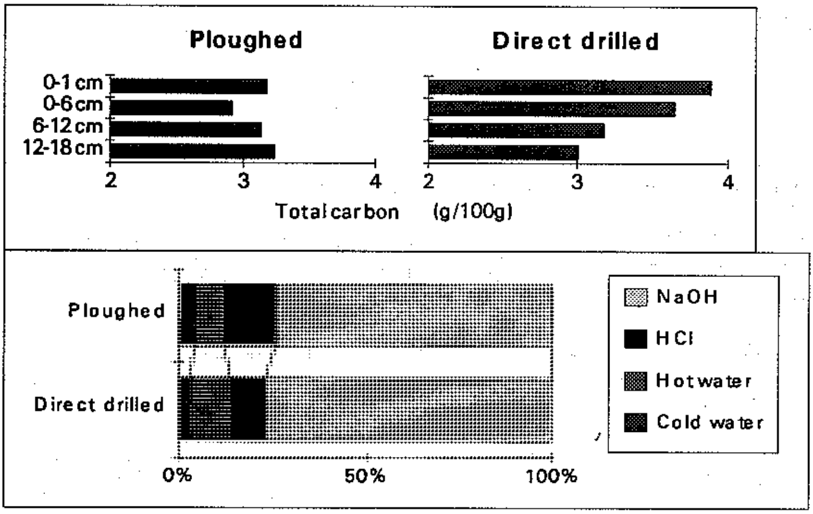

Fig. 3. Total carbon (g/100g) in topsoil (top) and soil carbohydrate composition at 0-1 cm depth, in 1990 for the long-term ploughed and direct drilled treatments (bottom). On the lower graph, the key refers to the carbohydrate extractants.

The structural stability and resistance to compaction of the direct drilled surface soil were considerably better than ploughing. However, there was no evidence that the structure of the ploughed soil deteriorated significantly during the experiment. The final profile carbon levels (Fig. 3) are little different to those measured in 1979. Also, earthworm populations measured over the same period changed little (11) indicating that both properties had by 1979 reached values which can be regarded as equilibria. In direct drilled plots organic matter below 5 cm depth increased a little between 1979 and 1988 due to earthworm activity.

CONCLUSION

At this site, conventional ploughing and drilling is the most reliable tillage system for continuous cereal production. The environmental benefits of direct drilling such as improved soil structure, faunal activity and carbon fixation are offset by the need for weed control by herbicides. The use of direct drilling by farmers is unlikely because the possible economic advantages of reduced fixed costs and labour (13) are negated by the extra costs of weed control, greater management requirement and greater risk of crop failure. Other non-ploughing systems could be used in an 'environmentally friendly' (sustainable) agricultural system provided they were within a rotation.

The experiment suffered in its latter stages from a decline in interest in soil tillage and consequent reduction in expenditure and from localised deterioration of drainage under non-ploughing treatments. However, its long term availability and comprehensively characterised and monitored soil and site conditions stimulated a number of associated experimental studies. Moreover, differences in the soil conditions induced over a prolonged period make it potentially useful for monitoring long-term changes under set-aside conditions.

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THE EFFICIENCY OF SEVERAL TILLAGE SYSTEM IN THREE COURSE CROP ROTATION

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ABSTRACT

The field experiment in three-course crop rotation was conducted to evaluate the effect of different ploughing depths on crop yield and some soil characteristics.

INTRODUCTION

The effects of different ploughing depths on crops yield and soil properties like bulk density, penetrometer resistance,water retention,ODR and others depend on agroecological conditions(1, 3, 7).Generally speaking prolonged shallow ploughing results in increasing the bulk density and penetrometer resistance of the upper soil layers(1, 2, 4, 5) while the reverse is true for deep ploughing or subsoiling.The effect of subsoiling on soil properties is sometimes short lasting(6).

MATERIAL AND METHODS

The field experiment was carried out in the years 1990-1993 in Experimental Sta.Baborowko near Poznan in Middle Poland on brown soil, sandy loam spread on light loam of glacial origin.Acc.to the polish standards the soil is classified as a wheat very good soil suitability complex of IIIa valuation class.The agriculture in this region is intensive in spite of unfavorable climatic conditions.The average rainfall is 500 mm and the average temperature 8.1 Celsius degree.The weather conditions in 1990 and 1991 were near to average figures while the year 1992 was the driest and hotest in the last decade with the evapotranspiration rate high over the rainfall in vegetation period.In 1993 rainfall exceeds the long term averages and the soil water retention was partially restored.
In crop rotation:sugar beets - oats - winter wheat , three soil tillage methods were compared:surface,conventional and subsoiling.In surface tillage paring plough,cultivator and rototiller with sowing set on working depth no more than 1o cm were used.In conventional method the soil was ploughed for 25 cm, cultivated with cultivation set and the seeds were drilled with pneumatic drill.In the third tillage system the soil was additionally subsoiled every third year on the depth of 60 cm.The subsoiling has been done for each crop starting the rotation and than regulary for sugar beet.Every year the crop yield, yield components and the costs of several tillage systems were analysed with the use of one-way Anova (Statgraphics Plus version 7) method.In 1993 the natural and actual soil bulk densities and the soil resistance were measured in each treatment and replication.

To measure the soil actuall density the Kopecky,s cylinders with the capacity of 100 cm^3 was used .The soil natural density was calculated with the use of the formula proposed by Wojtasik(8):

$$\varrho n = o + f(g) + f(z) - f(c) + f(Ca)$$

where: ϱn - soil natural bulk density in Mg*m^-3

ϱ o - soil bulk density in margin conditions: g = 0 , z = 0, c = 0 and Ca = 0

g - the granulometric bulk density component depended on the relation between the soil particles of the diameter 500 - 100 um and the particles < 1 um

z - depth in the soil horizon in dm

c - organic carbon in the soil in %

Ca - calcium carbonate in the soil in %

The soil granulometric composition was analysed by hydrometric method with the separation of sand fraction on the sieves,organić carbon by Tiurin method and calcium carbonate content by Scheibler method.

RESULTS AND DISCUSSIONS

Crops yield

The yield of main crops products are presented on Fig.1 a, b , c.

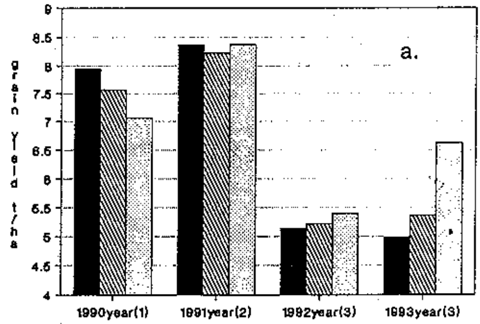
Figure 1. The yield of crops depending on soil tillage system

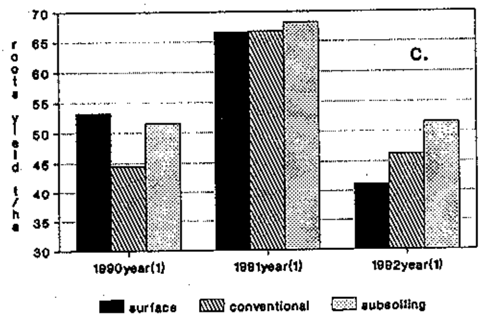
a. winter wheat

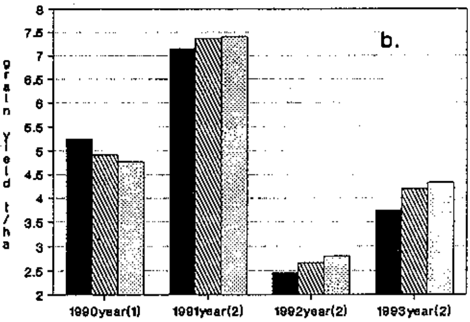
b.oats

c.sugar beet

In the parentheses the year from the subsoiling.







The plant yield depended on the interaction of soil tillage methods with the weather conditions and with the elapse of time from the beginning of the experiment.In the first year of the rotation (1990) the highest yields were recorded on the surface tillage and the lowest on conventional and -or subsoiling tillage.There is reminded that the subsoiling has been done for each crop starting the rotation.The worse effect of subsoiling can be explained by direct effect of soil loosening on the rate of seed emergence and early seedlings development.This rate was lower in the conventional tilllage and subsoiling treatment and more sparsely crop stand up to harvest time was observed.The more dense crop canopy in surface tillage system in the good weather conditions of 1990 developed a higher yield of sugar beet roots and cereals grain.In the second year of the rotation (1991) there was no significant difference between the yield of crops grown in several tillage systems with the slight tendency for higher yield of sugar beet roots and oat grain in the treatment with the conventional and - or subsoiling tillage.The oat and winter wheat succeeded in the second year after subsoiling and the water deficit was slightly higher than in 1990.The sugar beet stand was also sparser on conventional and subsoiling tillage but the obviously better soil water regime leveled off this difference in comparison to surface tillage.

In 1992 and 1993 the yield of crops grown on subsoiled plots were significantly higher in comparison to surface tillage.The yield differences of 0.3 - 1.5 Mg *ha^-1 of cereals grain and more than 1o Mg*ha^-1 of sugar beet roots on behalf of subsoiling were recorded.It has been already mentioned that the weather conditions in 1992 were particularly unfavorable for all crops due to prolonged drought period and vey high water deficit.In 1993 the weather was much better but the reserves of soil water have been restoring slowly and gradually.

In the system of soil tillage with the subsoiling higher labour input by some 2.5 working hours and energy input by some 3.0 tractor hours as well as fuel consumption by 2o dm^3 per hectar were required.The cost of these inputs correspond to the value of 0.2 Mg of cereal grain and 0.5 Mg of sugar beet roots.By comparison the conclusion can be drawn that this system of soil tillage is fully profitable if it is employed regularly for several years.

The soil physical properties

The differences in crops yield between the surface and conventional or conventional with the subsoiling tillage can be partly explained by soil bulk density and penetrometer resistance (Fig.2 a, b,c and Fig 3 a, b, c).In the treatments with deep ploughing and-or subsoiling the actual soil density was much closer to the natural density than in treatment with surface cultivation.The sum of standard deviation of actual from natural density as the average value for 5 soil horizons was 0.37 Mg*m^-3 for surface,0.32 Mg*m^-3 for conventional and only 0.28 Mg*m^-3 for subsoiling tillage.Particularly in the soil horizon 2.5 - 4.0 dm the actual soil density was much closer to the natural one in the treatments with deep ploughing and subsoiling.In the previous research it was shown that soil at the natural density has the highest available water retention and ODR value hence it is more productive(8).

Penetrometer resistance reflects the differences in soil properties between the treatments with surface and deep ploughing even better than the bulk density.On the depth 1 - 2.5 dm the resistance of the soil cultivated on the surface was of 100 N*cm^2 higher in comparison to the conventional tillage or subsoiling.Subsoiling eliminated very effectively the plough pan on the depth 2.5 - 3.0 dm and loosened the soil on the working depth of 6.0 dm.

The depth of soil tillage influenced also the nutritional status of the crops in respect to nitrogen (Tab.1)

Figure2. The soil natural and actual densities depending on the tillage system.

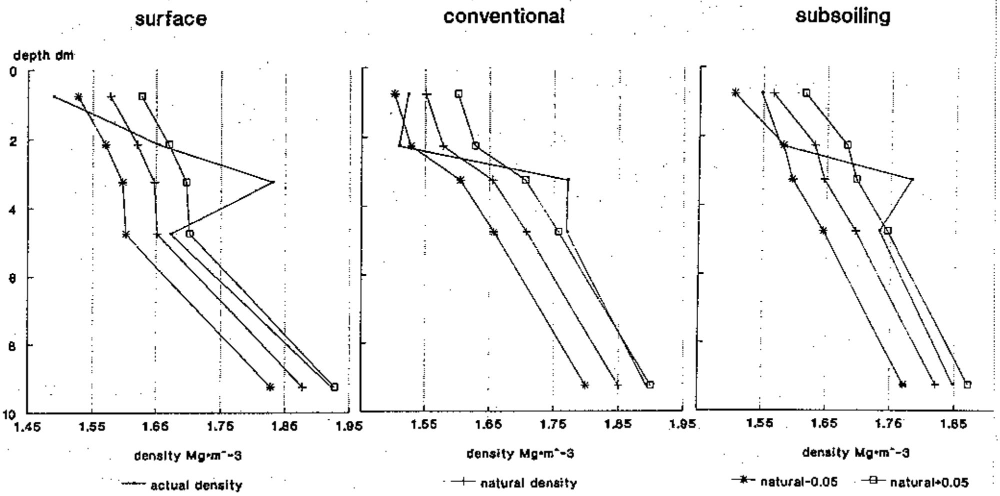


Figure 3. The soil penetrometer resistance depending on tillage system.

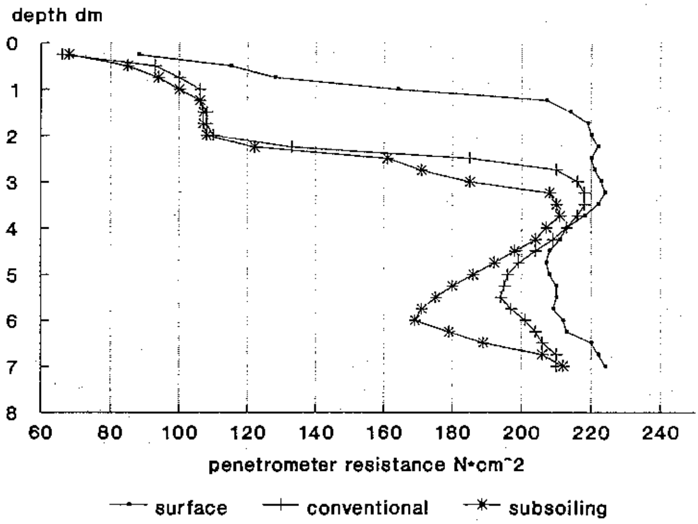


Table 1 Nitrogen content in plants in indicatory growth stages .Average of 3 - 4 years.

Tillage Treatment	Nitrogen Form	Unit	Nitrogen content in the crop sugar beet	oats	winter wheat
Surface	N-total	% d.m	4.05	3.25	3.19
	N-NO3	mg*dm^3	675	465	100
Conventional	N-total	% d.m	4.24	3.44	3.27
	N-NO3	mg*dm^3	697	507	115
Subsoiling	N-total	% d.m	4.47	3.56	3.31
	N-NO3	mg*dm^3	965	645	130

The content of total and nitrate nitrogen in the shoots of cereals (in the shooting stage) and in the leaves of sugar beets (in 8 leaves stage) was higher in the treatments with deep tillage comparing to shallow cultivation though in the experiment the uniform and optimal nitrogen dose was applied.
In the course of the experiment the differences in weed infestation among the tillage treatment were not observed.

CONCLUSIONS

1.The productivity of intensive crop rotation is higher on conventional and conventional with the subsoiling tillage than on shallow cultivation.In spite of lower labour and fuel input the shallow cultivation is not profitable.
2.The soil cultivated to the depth of 10 cm only is more compacted and its actual density is far outside the range of the natural density.
3.Besides the unfavorable physical conditions the reason for lower productivity of surface cultivated soil is the worse nitrogen nutritional status.

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TILLAGE AND TRAFFIC FOR SUSTAINABLE SUGARCANE PRODUCTION

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ABSTRACT

A field trial was conducted with two sugarcane varieties (Q117, Q138) to determine the effect of zero tillage and subsequent harvest traffic on soil physical properties and sugarcane growth. Treatments consisted of wheel traffic directly over the planted row, 0.1m from the row and down the middle of the inter-row, by fully laden cane transportation equipment immediately after harvest. Undisturbed cores were extracted for determination of saturated hydraulic conductivity and bulk density. Soil cone resistance was measured in the field. All measurements were made before and after impact. Stalk numbers and heights were recorded regularly to assess treatment effects. Experimental design was a split-plot, with the main plot being position of wheel impact and the split being on varieties.

Saturated hydraulic conductivity decreased, bulk density increased and soil cone resistance increased after wheel traffic. The order of change was row > near-row > inter-row impact. Stalk numbers and heights indicated no difference due to treatment, but there was a significant varietal difference. Variety Q117 produced greater shoot numbers than Q138 for each treatment in the order of position of impact; row > near-row > inter-row. These differences became smaller as the crop matured.

Matching sugarcane row spacing with equipment track width may reduce soil compaction under the row and minimise direct crop damage due to traffic during harvest. This should enhance productivity by increasing ratoon length and maintain sustainability by reducing soil structural degradation.

INTRODUCTION

Sugarcane is grown as a monoculture in the Australian tropics and sub-tropics. The crop is planted in 1.5 m wide rows. Several harvests are taken from the initial planting. Thus a crop cycle consists of a plant crop harvested 12 to 14 months after planting and an average of four annual ratoon crops.

In mechanised agriculture, soil compaction reduces crop yields (1). Mechanical harvesting, by increasingly bigger harvesters and haulouts, has been linked circumstantially with the yield plateau in the Australian sugar industry since 1975. The below-ground cane stool and soil structure can be damaged during harvest by hauling equipment, especially under wet conditions (2). Poor crop growth attributed to traffic damage is identified annually, but overall yield losses have not been quantified.

Yield usually declines with successive ratoon crops (3) which may be consistent with restricted root systems due to soil compaction. A large proprtion of the harvest in North Queensland is carried out when the soil is moist, which is conducive to soil compaction. The cumulative effect of harvest traffic on soil compaction and subsequent ratoon growth is unknown.

This work was undertaken to determine the effect of position of traffic in relation to the crop row on crop yield, and to determine the cumulative effect of harvest traffic on soil physical properties, stool damage and ratooning in consecutive ratoon crops.

MATERIALS AND METHODS

A field trial was established at Tully Sugar Experiment Station (17°S',59'S,145°55'E) on a soil with principal profile form Uf 6.34 and soil taxonomy classification as Dystropept (4.5)).

Two sugarcane varieties (Q117, Q138) were grown in plots consisting of four rows (20m long) spaced at 1.9 m. Treatments consisted of wheel impact directly on the row, 0.1m from the row and down the middle of the inter-row (0.3 m from the row), using fully laden cane transportation equipment (8t in total) immediately after harvest. There were five replicates.

Depending on the treatment, undisturbed cores (0.075 m dia. x 0.05 m high) were taken from the cane row, near-the-row and from the middle of the inter-row to a depth of 0.2m (for the plant crop) and 0.3 m (for the first ratoon) in 0.05 m increments. The cores were used to determine saturated hydraulic conductivity (constant head method) and bulk density.

Field measurements consisted of soil cone resistance (Bush recording penetrometer 12.8 mm dia.) and gravimetric water content to a depth of 0.5 m. Surface relief was measured using a recording profilemeter (Rimik, Toowoomba). All measurements were made before and after harvest for the plant crop and then after harvest for each ratoon crop.

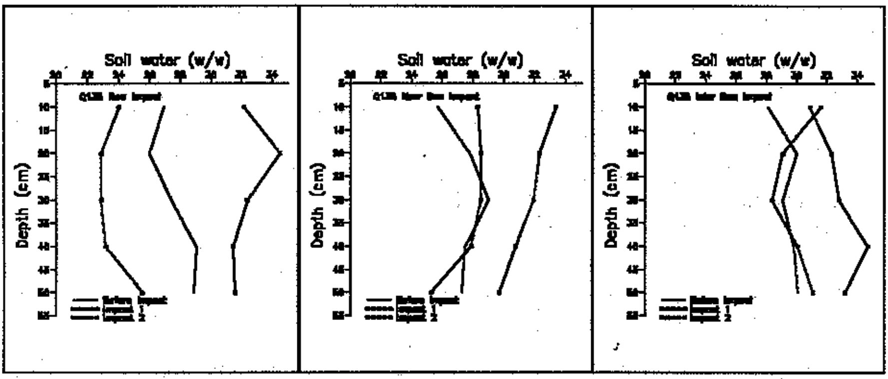
Crop response was assessed by counting stalk numbers and measuring stalk height on a regular basis. Final yields were recorded for both the plant and ratoon crop.

Experimental design was split-plot with the main plot being the position of wheel impact, and the split being varieties. Results were analysed using standard ANOVA.

RESULTS AND DISCUSSION

Soil water content at the time of traffic impact varied making comparisons across seasons difficult. The plastic limit (PL, Altenberg) was 32%, while the maximum bulk density of 1.5 g/cm^3 resulted at a water content of 23% (Proctor test). For the first time of impact soil water content was close to or slightly above 23%, while at the second impact it was close to the PL (Fig. 1). The soil water content (at the time of each impact) was in the range where the soil was susceptible to compaction.

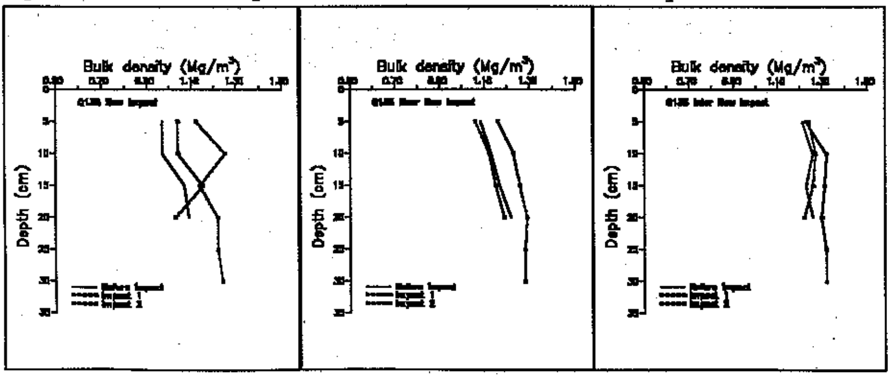
Figure 1. Initial soil water content at impact for each treatment



Bulk density

Bulk density increased after each impact and with depth (Fig. 2). The degree of change depended on the position of impact with less change occurring with near-row and inter-row impacts compared with row impact. This is due to the fact that impacts are applied after harvest, so the near-row and inter-row positions had higher bulk density from previous traffic during harvest. Similar results have been observed in South Africa and South America (2,6), although soil types, equipment and impact imposition were different

Figure 2. Effect of position of traffic on bulk density

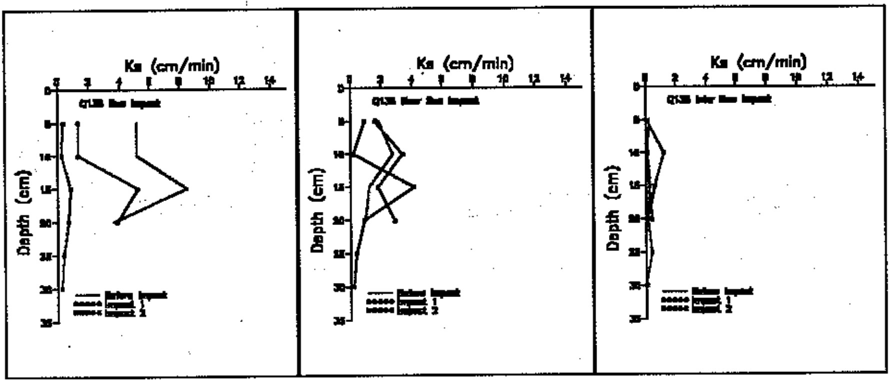


to that used in the current study. It is yet to be determined whether these densities limit root growth.

Saturated hydraulic conductivity

Saturated hydraulic conductivity reflected the bulk density results, in that conductivity decreased after impact (Fig. 3). Again the greatest change occurred with the row impact compared with the near-row and inter-row impact. The reduction in conductivity has implications for erosion and run-off. In tropical areas high intensity summer rain can rapidly fill the profile and result in significant run-off and erosion on slopes. The low conductivities will slow water redistribution in the profile and will also reduce water

Figure 3. Effect of position of traffic impact on satd. hydraulic conductivity



movement and fertiliser uptake. Root growth may be restricted to the surface layers if subsoil is compacted and tillage only ameliorates plough pan compaction increasing the risk of water stress later in the season, or water logging during excess rainfall.

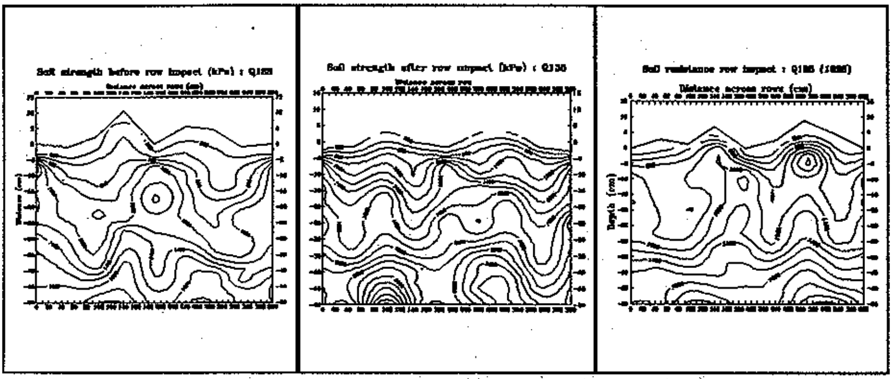
Soil cone resistance

Soil cone resistance measurements were variable between seasons, due to differences in soil water content at the time of measurement (Fig. 4). Zones of increasing resistance appear to move relative to the surface. For example with traffic on the row treatment, a zone greater than 1800 kPa occurred around 40 cm depth before traffic. After the first traffic immediately after harvest, this zone developed columns under the row at a depth of 15-20 cm. However, after the second trafficking immediately after harvest 12 months later, this zone again occurred at 40-45 cm depth (still with evidence of columns under the row) (Fig. 4).

This observation was similar for all positions of trafficking, with zones of greater resistance occurring directly under the position of traffic. Torres and Villegas (2) have made similar observations.

It is unknown whether these cone resistance levels restrict root growth. However the results show the dynamic nature of changes in soil resistance with time and soil water content. Thus in one season root growth may be restricted to relatively shallow soil depths, while in another season the depth available for exploitation will be greater. This may explain the transient nature of soil compaction, in that the effect is evident one year,

Figure 4. Effect of traffic on soil cone resistance (kPa)



but not the next.

Shoot numbers and plant heights

Traffic over the row resulted in fewer shoots compared with traffic near-the-row or in the inter-row for variety Q138 (Fig. 5). The reverse was observed for Q117. The reason for this difference is not known. However, later in the season the Q138 row traffic treatment had higher shoot numbers. There was, however, no significant difference in shoot numbers between treatments. The greater numbers of shoots observed after row traffic may be due to improved sett-soil contact , which may improve water relations.

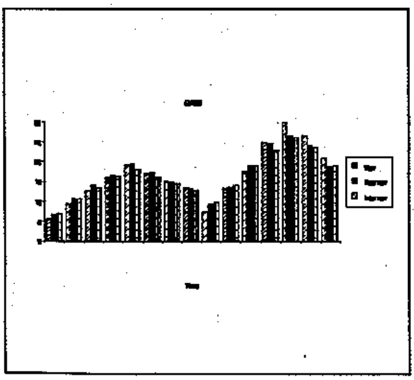


Figure 5. Effect of treatment on sheet numbers.

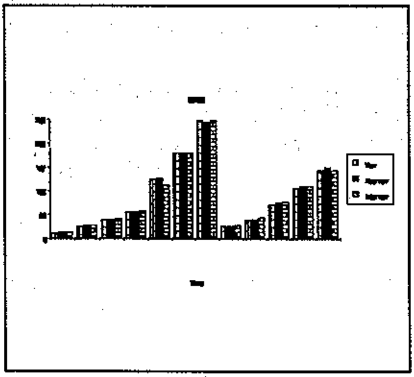


Figure 6. Effect of treatment on stalk heights.

Stalk heights were less after row traffic than with the other two positions of traffic (Fig. 6). Again there was no difference in stalk heights between treatments at any time of measurement. There were fewer and shorter stalks for the row treatment compared with the other treatments.

Crop yield

Traffic impact showed little effect on crop yield of first ratoon cane (Table 1). For Q117 the near-row and inter-row treatment yielded six and three percent higher respectively than the row treatment. There was little or no effect of treatment in the yield of the variety Q138.

Table 1. **Effect of position of traffic on cane yield (t/ha)**

Variety	Q117				Q138			
Treatment	Row	Near-row	Inter-Row	LSD	Row	Near-row	Inter-row	LSD
First Ratoon	108.5	115.6	111.7	ns	115.7	115.7	113.6	ns

Yield losses of up to 40 percent have been attributed to stool damage by harvesting traffic (5,6), which is much greater than that observed in this trial. This may be due to differences in varieties used, soil response to traffic and soil water content at the time of impact. Climatic conditions after impact would also affect following crop yields.

There appears to be a varietal difference in the response to treatment with Q117 yielding slightly lower than Q138 after trafficking. This may offer a means to maintain sustainability given the current system of management, by planting varieties able to better withstand traffic impact.

General discussion

To reduce soil compaction lighter machinery should be used, high flotation tyres fitted and harvesting undertaken under dry conditions (6). Under tropical conditions it is not always possible to harvest under dry conditions and little is known of the cumulative effect of traffic on soil properties at a moisture content between "dry" and "wet" (i.e. no damage and deep rut formation), a condition that occurs more often than not.

It has been suggested that to reduce direct damage to the stool during harvest all traffic be confined to the inter-row. The main problem with this is the incompatibility between current crop row spacing and machinery track width. The simplest solution is to match the two, thus ensuring traffic is always in the inter-row. This should reduce direct stool damage and confine soil structural damage which preserves the soil structure in the row thus maintaining productivity and sustainability.

It is speculated that by matching sugarcane row spacing with equipment track widths, direct crop damage should be minimised and soil compaction under the row reduced.

This should enhance productivity by increasing the ratoon length and improve the sustainability of the sugar industry in Australia by reducing soil structural degradation.

CONCLUSIONS

At this early stage of the trial it can be concluded that traffic has had little effect on crop yield. Traffic has increased bulk density, reduced saturated hydraulic conductivity and increased soil cone resistance under all positions of impact. The greatest change was in the order row > near-row > inter-row.

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NARROW STRIP CROPPING SYSTEMS WITH RIDGE TILLAGE TO REDUCE EROSION LOSSES AND ENERGY INPUTS WHILE OPTIMIZING PROFITABILITY

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ABSTRACT

Current corn (*Zea mays* L.) and soybean (*Glycine max* L.) production practices used by many US farmers are considered to be quite energy intensive while allowing excessive soil erosion losses. An experiment was conducted at two locations in southern Minnesota on a glacial till soil to investigate narrow (4.57 m), alternate strip systems planted on ridges (ridge tillage). A 3-crop system of corn, soybean, and wheat was compared with a 2-crop system of only corn and soybean. Rows were oriented N-S at one location and E-W at the other. Corn production was increased by 3% with E-W rows and 13% with N-S rows due to the positive border effects in the narrow strips. Soybean yields in strips alternated only with corn were reduced by 7% (N-S rows) and 10% (E-W rows) due to competition and shading by the corn. When grown in a 3-crop system, soybean yields were reduced only by 3% (N-S rows) and 5% (E-W rows) because of less shading when bordered by wheat. Wheat (*Triticum aestivum* L.) yields were not influenced by the border crops. Grain moisture of the corn was slightly lower in the strips when planted in N-S rows compared to the whole-field average. Erosion control as measured by surface residue coverage in the 3-crop system was superb. The goals of a more sustainable form of agriculture appear to be met with the 3-crop system planted in a N-S row orientation on ridges.

INTRODUCTION

Alternating narrow strips of tall and short crops has been practiced infrequently for centuries, especially in small, intensive production systems and in agriculturally underdeveloped countries. The goal has been to use sunlight more efficiently for maximizing crop production. In the USA, narrow, alternate strip cropping systems have been receiving greater attention recently, probably because more reduced tillage systems (no tillage and ridge tillage), which more easily facilitate these strips, are becoming more popular. These aesthetically pleasing cropping systems are touted as sustainable systems that reduce chemical and energy inputs, minimize pest activity, and improve erosion control and net profit.

Several studies conducted in the eastern and midwestern sections of the USA show considerable variation in production among years and locations (1). Experiments conducted in Virginia by Alexander and Genter (2) showed corn produced in 2-row strips to yield about 30% more than corn grown as a sole crop while soybean yields were not different.

More recent studies have shown that improved corn yields in the borders of narrow strips are offset by reduced soybean yields. West and Griffith (3) found 8-row strips to increase outside row corn yields by 25.8% while the outside rows of soybeans in these strips were decreased by 26.6% in their Indiana studies. Strip yields of corn averaged 1.26 Mg ha^{-1} more than non-stripped corn while stripped soybean yields were 0.40 Mg ha^{-1} less than unstripped soybean. Minnesota studies reported by Crookston and Hill (4) showed similar results and they concluded that total land use efficiency (LUE) for two-crop stripped systems was reduced. However, Pendleton et al. (5) concluded that the advantage to strip cropping would depend on relative potential yields and prices of the two crops.

Incorporating narrow strips of wheat into the traditional corn-soybean sequence should reduce the negative border effects of corn on the adjacent soybean rows without sacrificing wheat yields. Wheat planted on the north side of corn and the south side of soybean in east-west rows will allow optimum sunlight for soybean. Wheat, a cool season crop, will not be shaded as it heads out before corn gets tall enough to shade it. In addition, wheat added as a third crop to this system should break up disease and insect cycles associated with the 2-crop system, will allow interseeding of legumes to fix N, and should curtail soil erosion considerably. Potential erosion on a Sharpsburg silty clay loam in Nebraska was estimated by Francis et al. (1) to be only 13% of maximum erosion when a small grain was introduced into a contour strip corn-soybean rotation.

The objectives of this study were to: (i) determine the production and economic impact of wheat introduced into a corn-soybean alternate strip system planted on ridges and (ii) determine the potential of this 3-crop system to minimize energy inputs, pest pressures, and soil erosion losses.

MATERIALS AND METHODS

Studies were started in 1991 in Waseca Co. with east-west rows and in Freeborn Co. with north-south row orientation. In the east-west rows, soybean strips were always located south of the corn strips with the wheat on the south side of the soybean. This arrangement minimized shading at the strip borders because the wheat on the north side of the corn was almost mature by the time of shading by the corn. In the north-south rows, wheat was always located on the east side of the corn strips while soybean was on the west side of the corn. The soil type at both locations was a Webster clay loam (fine-loamy, mixed, mesic Typic Haplaquoll). Soybean was grown at both sites in 1990. All crops were planted in 4.57 m wide x 36.6 m long strips on ridges. Corn was planted in 76-cm rows at a rate of 74620 plants ha^{-1} in rows 2 - 5 and 88960 plants ha^{-1} in the outside rows (1 & 6). Nitrogen as ammonium nitrate was broadcast-applied by hand at rates of 0, 45, 90, and 135 kg N ha^{-1} to plots measuring 6 rows wide by 9.15-m long in each strip. Weeds were controlled with a 37-cm band-application of alachlor and cyanazine and ridge-till cultivation. Hand-harvest grain yields were obtained from a 7.6-m section within each row of each plot.

Soybean was planted at a rate of 410000 plants ha^{-1} in 76-cm wide rows. Weeds were controlled with 37-cm wide band-applications of alachlor (preemergence) and imazethapyr (post emergence) and by ridge cultivation. Each individual row was harvested with a plot combine.

Spring wheat was planted at a rate of 105 kg ha^{-1} with a minimum-till drill in 20-cm wide rows after a broadcast-application of urea at 56 kg N ha^{-1}. Broadleaf weeds, when present, were controlled with a broadcast-application of bromoxynil. Wheat grain and straw yields were obtained each year by harvesting 1.5-m wide, full-length sections of each strip. Additionally, yields were taken from each row by hand-harvesting a 4.6-m long section.

These 3-crop strip rotations were compared within each replication to the corn-soybean alternate strip system and to continuous corn which was planted in 18-row wide blocks. All treatments were replicated four times in a randomized, complete-block design.

RESULTS AND DISCUSSION

The yield advantage of the narrow strips for corn in the 3-crop (wheat-corn-soybean) rotation was 0.3 Mg ha^{-1} in the E-W system and 1.1 Mg ha^{-1} in the N-S row orientation compared to the whole-field averages (Table 1). In the E-W rows, row 1 (next to wheat) and row 6 (next to soybeans) yielded 6 and 18% higher, respectively, compared to the average of the center two rows, which were assumed to represent the whole field yield. When the rows were oriented N-S, the yield advantage was 32 and 34% for rows 1 and 6, respectively, compared to the center two rows.

Table 1. Corn grain yield in a C-Sb-W rotation as influenced by row position and direction†.

Row Direction	Row/Position 1	2	3 & 4	5	6	Yield Adv. of 6-row strip‡
	Mg ha^{-1}					
E-W rows	10.0	8.9	9.4	9.2	11.1	0.3
N-S rows	11.2	9.0	8.5	8.8	11.4	1.1

† 3-yr (1991-1993) averages at the 135-kg ha^{-1} N rate.
‡ Yield advantage of 6-row strip compared to the center two rows, which are assumed to represent the whole-field situation.

Soybean yields were depressed 0.41 Mg ha^{-1} (16%) for row 1 (next to corn) and 0.14 Mg ha^{-1} (6%) for row 6 (next to wheat) compared to the center two rows in the E-W row orientation (Table 2). In N-S rows, row 6 (next to wheat) yielded only 0.02 Mg ha^{-1} less compared to the center two rows while the row bordering corn (row 1) suffered 0.41 Mg ha^{-1} (19%) yield loss compared to the center two rows. The strip yields were 0.13 and 0.07 Mg ha^{-1} less for the E-W and N-S systems, respectively, compared to the whole-field averages.

Table 2. Soybean seed yield in a C-Sb-W rotation as influenced by row position and direction†.

Row Direction	Row/Position 1	2	3 & 4	5	6	Yield Adv. of 6-row strip‡
	Mg ha^{-1}					
E-W rows	2.10	2.27	2.51	2.53	2.37	-0.13
N-S rows	1.74	2.09	2.15	2.23	2.13	-0.07

† 3-yr (1991-1993) averages at the 135-kg ha^{-1} N rate.
‡ Yield advantage of 6-row strip compared to the center two rows, which are assumed to represent the whole-field situation.

When soybean was alternated only with corn in the 2-crop system, yields were decreased much more severely (Table 3). Outside rows (rows 1 & 6) bordering corn yielded 23% less

(0.56 Mg ha^{-1}) than the center two rows in the E-W system and 18% less (0.39 Mg ha^{-1}) in the N-S system. The soybean row on the N side of corn (E-W system) and E side of corn (N-S system) yielded 33 and 26% less, respectively, than the center two rows. Seed yields for the 6-row alternate strips were decreased by 0.24 Mg ha^{-1} in the E-W system and 0.15 Mg ha^{-1} in the N-S system compared to the whole-field averages.

Table 3. Soybean seed yield in a C-Sb rotation as influenced by row position and direction†.

Row Direction	Row/Position 1	2	3 & 4	5	6	Yield Adv. of 6-row strip‡
	Mg ha^{-1}					
E-W rows	2.09	2.24	2.42	2.27	1.62	-0.24
N-S rows	1.63	2.08	2.21	2.17	2.00	-0.15

† 3-yr (1991-1993) averages at the 135-kg ha^{-1} N rate.
‡ Yield advantage of 6-row strip compared to the center two rows, which are assumed to represent the whole-field situation.

Wheat yields averaged over the three years were not affected greatly either by the corn or soybean borders (Table 4). The largest yield loss (<0.3 Mg ha^{-1}) occurred along the west one-third of the N-S strips. Yields taken from the individual rows (data not shown) indicates some yield reductions when rows occur directly in the valleys between the ridges, especially in the wheel-tracks, compared to the rows on top of or on the shoulders of the ridges. Yields of the outside rows were not greatly affected by the corn and soybean borders.

Artificial drying of corn grain is one of the highest energy consuming processes in corn production. Thus, moisture content at harvest was measured to determine if row direction and row position within the strips affected overall grain moisture content and whether the "strip" moisture was different than the "whole-field" moisture. Moisture at harvest was impacted by row position but the nature of this effect was affected by row direction (Table 5). In the E-W rows, grain moisture was about 3 points higher in the north row and 3 points lower in the south row compared to the center rows. Thus, on average, grain moisture from the strip was not different than from a whole field. On the other hand, when in N-S rows, both the outside two east and two west rows contained about 2 points less moisture than the center two rows. As a result, overall average grain moisture from the N-S strips was lower than from a whole field; thereby saving some drying energy and costs.

Table 4. Border effects on wheat yields as influenced by row position and direction†.

Row Direction	N⅓ or E⅓	Center⅓	S⅓ or W⅓	Yield Adv. of 15' strip‡
	Mg ha^{-1}			
East - West	2.89	2.85	2.75	-0.02
North-South	2.87	2.83	2.55	-0.08

† 3-yr (1991-1993) averages
‡ Relative yield advantage of the 4.57-m strip compared to the center 1.52 m, which is assumed to represent the whole-field situation.

Table 5. Corn grain moisture content at harvest as influenced by row position in 1992†.

Row Direction	Row/Position				
	1	2	3 & 4	5	6
	%				
E-W rows	35.1	31.7	32.0	30.0	28.3
N-S rows	25.8	25.6	27.5	25.5	25.3

† Averaged over all 4 N rates.

Surface residue coverage prior to planting was ideal for all crops (Table 6). After planting, residue coverage was still >30% following corn and wheat. Residue coverage after soybean was only 24%, but this was offset by mid-May with a well-established stand of wheat capable of providing excellent erosion control in this 3-crop system.

Table 6. Surface residue coverage (2-year average)† as influenced by previous crop at Freeborn Co.

Previous crop	Before planting	After planting
	%	
Corn	72	41
Soybean	59	24
Wheat	82	35
Wheat + Alf.	87	54
Wheat + Vetch	90	49

† 1992-1993 averages

CONCLUSIONS

1. Erosion control goals as measured by surface residue coverage were satisfied well with the narrow, alternate strips of corn, soybean, and wheat.

2. Corn yields were enhanced in both the 2- and 3-crop systems due to increased yield of the border rows. Yield increases were greater in the N-S rows compared to the E-W rows.

3. Soybean yields were decreased slightly in the 3-crop system and markedly when alternated only with corn in the 2-crop system. Yield decreases were greatest in the E-W rows.

4. Wheat yields were not influenced either hy corn or soybean borders.

5. Introducing wheat as a third crop into the traditional 2-crop system minimized negative border effects on soybeans and reduced soybean cyst nematode egg populations (data not shown).

6. The 3-crop alternate, narrow strip system planted on ridges in a N-S row orientation appears to meet sustainability goals by being profitable, by reducing artificial grain drying energy costs, and by limiting the activity of certain pests associated with the traditional corn-soybean rotation.

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EVALUATION OF MINIMUM TILLAGE ON SORGHUM AND MAIZE IN IRRIGATED VERTISOLS OF SUDAN

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ABSTRACT

This research was conducted at Gezira Research Station where the soils are cracking heavy clay Vertisols and the climate is semi-arid. The study comprised two separate experiments: one on sorghum and the other on maize. Each experiment included five tillage treatments with four replications in a randomized complete block design. The five tillage treatments were: Minimum tillage (MT), disc harrow, heavy disc harrow, chisel plow and disc plow + disc harrow + levelling.

Results showed that MT resulted in highest number of weeds and the highest percent weed ground cover for both crops. However, the response of the two crops in yield to MT was different. While sorghum showed no significant differences between MT and the other tillage systems, maize yield was significantly affected by MT.

INTRODUCTION

Sorghum is the staple food of Sudan. About 25% of the sorghum produced in Sudan is cultivated in the irrigated Vertisols of Central Clay Plain which include: Gezira, Rahad, Blue Nile and White Nile Agricultural Production Projects. Maize is traditionally cultivated along the banks of the Nile river in the Northern State. However, maize is considered as a new crop in the irrigated projects. These projects are characterized by semi-arid climate and heavy Vertisolic soils.

The main objective of tillage in these projects is to develop a desirable seed-bed and to control weeds. Tillage operations in these State owned production projects depend on cost and availability of machines. The most popular machines are the four body ridgers, disc harrows and disc plows. These machines are owned by the Government in addition to private companies and individuals. The cost of fuel and machinery had increased substantially during the last few years. For farmers to make profits, inputs must be efficiently used and managed. Tillage is one of the basic inputs that need to be manipulated. There is a growing trend by farmers towards minimum tillage as a mean of reducing cost of production. Unfortunately very few research work had been carried in this area.

The objective of this research was to compare the effects of minimum tillage on establishment, weeds, water use and yield of maize and sorghum.

MATERIALS AND METHODS

The experiment was conducted in 1992/93 season at Gezira Research Farm (GRS), Medani, Central State, Sudan. The previous crop was wheat, however, the surface was clean with very few wheat stubble. The soils at GRS are cracking heavy clay Vertisols, with 58-66% clay, very low water permeability, a pH of 8.5, poor organic matter (0.5%), deficient in Nitrogen (300-400 ppm), and low in available Phosphorus (2-4 ppm). The climate is semi-arid with mean annual rainfall of 400 mm, falling between June and September.

The design of the experiment was randomized complete block with four replications. Plots were 3.2 m x 20 m. Each crop had its separate experimental area with the same treatments. The treatments included:

A. Minimum tillage (MT), ridging only.
B. Disc harrowing (DH).
C. Heavy disc harrowing (HDH).
D. Chisel plowing (CP).
E. Disc plowing (DP) + disc harrowing + levelling.

All these treatments were followed by ridging 80 cm wide. Tillage implements used in this experiment included:

1. **Light disc harrow:** A tractor mounted, offset disc harrow with discs 55 cm in diameter. The effective width was 1.8 m. The front row was composed of nine notched discs while the rear was composed of nine plain discs.

2. **Heavy disc harrow:** A trailed offset Rome disc harrow with ten discs per row. The discs were 66 cm in diameter. This harrow was pulled by a D5B Caterpillar crawler tractor.

3. **Chisel plow:** A two row, nine chisel, tractor mounted plow with 28 cm between chisels.

4. **Disc plow:** A three bottom, tractor mounted, Baldan disc plow. Discs were 68 cm in diameter.

5. **Leveller:** A tractor mounted scraper

6. **Ridger:** A four bottom ridger/lister with 80 cm distance between bodies.

<u>Zea maize</u> (var. Mujtama'a) at a seed rate of 15.5 kg/Ha and <u>Sorghum bicolor</u> L. (var. Hageen Dura-1) at a seed rate of 4.8 kg/Ha were sown on the third week of July. Urea fertilizer at a rate of 2N (205 kg/Ha) was broadcast to both crops at seeding before the first watering. Harvesting was in December.

Both crops were irrigated every two weeks. A total of seven irrigations was applied. The plots were kept weed free.

Data collected included: effects on soil, weed data, water uptake, yield and yield components. Weed data was taken three weeks after emergence. Water uptake data was measured using Neutron Probe. Data were collected for each irrigation cycle at 15 cm increments to a depth of 60 cm.

RESULTS AND DISCUSSION

A. Effects of tillage on soil:

Minimum tillage is done by two ridging operations. These are ridging and split-ridging. This caused the least manipulation of the soil and was the least expensive treatment. The disc harrow operation resulted in manipulating the soil to a depth of 8-10 cm. The heavy disc harrow operation caused mixing and pulverization to a depth of 15-18 cm, while the chisel plow caused cutting to a depth of 10-12 cm. The disc plow was considered as a primary tillage operation. It was followed by disc harrowing and levelling. This was the most expensive treatment. It was noticed that residue incorporation was best on the disc plowed area. All these treatments were followed by 80 cm ridging. The field view after ridging was almost the same for all treatments.

B. Effects of tillage on weeds:

Results showed that the two crops responded differently at the different tillage systems. The number of weeds on sorghum were about one third of the number of weeds on maize. However, the percent weed ground cover was the opposite. The percent ground cover on maize was about four times that number on sorghum (figures 1 and 2).

i. **Sorghum:** Results showed that minimum tillage treatment resulted in the highest number of weeds (30 plants/m^2) and the highest percent ground cover (100). On the other hand the chisel plow resulted in the lowest number of weeds/m^2 (20) and the lowest % ground cover (63).

ii. **Maize:** Minimum tillage resulted in the highest number of weeds/m^2 (98) and the highest percent ground cover (26). The least number of weeds were at the disc harrow treatment (65). Percent weed ground cover was similar for the other treatments.

C. Effects of tillage on water uptake:

The primary effect of tillage was observed on the amount of available water stored in the profile (0-60 cm) depth. The least amount of water stored was found with minimum tillage (table 1). The pattern of uptake reflects the general distribution of the root

FIGURE 1. EFFECT OF TILLAGE ON NUMBER OF WEEDS

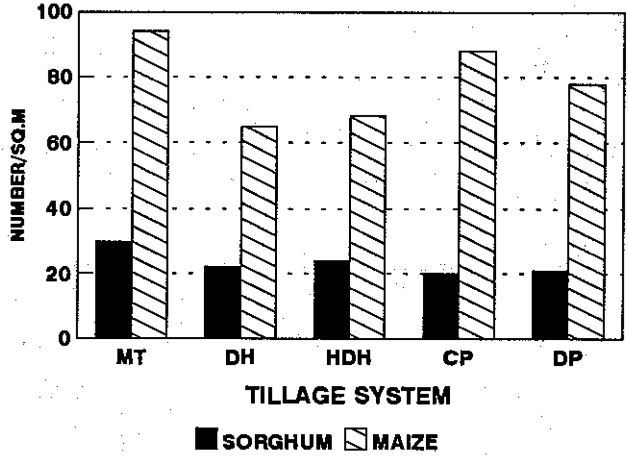
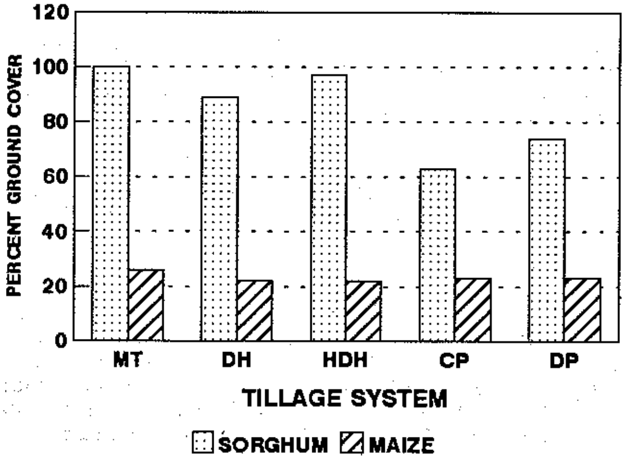


FIGURE 2. EFFECT OF TILLAGE ON PERCENT GROUND COVER



system and depth of tillage. With minimum tillage more than 70 % of the water uptake was from the 0-30 cm layer indicating that the bulk of the root system was confined to this layer. Water uptake for the same layer with disc plowing was about 58 % which means that the plant root system was able to extract water from deeper layers.

Consumptive use of water was greater under chisel plow for both crops. Less water was used under minimum tillage. The high consumptive water use of maize was reflected in higher yields, With regard to water use, minimum tillage was performing similar to the other treatments. However, the effect of tillage on consumptive use of sorghum was not clear. This suggests that with the pattern of irrigation adopted, sorghum was not water stressed regardless of the tillage system used.

Table 1. Water uptake data.

TREATMENT	Water stored mm		% water uptake 0-30 cm		Consumptive water used, mm	
	Sorghum	Maize	Sorghum	Maize	Sorghum	Maize
Min Tillage	114	76	71	75	461	478
Disc Harrow (DH)	126	94	66	68	456	486
Heavy Disc Harrow	130	108	68	68	471	496
Chisel Plow	130	120	62	65	483	506
Disc Plow+DH+ Levelling	129	118	58	64	475	513

D. Effects on establishment and yield:

i. **Sorghum:** Plant population density range from 42 860 to 51 670 plants/ha. The disc harrow treatment resulted in a significantly higher plants density when compared to the disc plow treatment. There were no significant differences between the other treatments (table 4).

Yield obtained by the minimum tillage were not significantly different than the other treatments. Yields ranged from 1688 kg/ha for the disc harrow treatment to 969 kg/ha for the disc plow treatment.

ii. **Maize:** Results showed that plant density ranged from 32 190 to 36 640 plants/ha for the minimum tillage and disc harrow respectively (Table 2). Statistical analysis showed that there were significant differences in yield. Minimum tillage resulted in a significantly (P = 0.05) lower yield (1808.8 kg/ha)when compared to the chisel plow treatment (2796.5 kg/ha). There was a 55 % increase in yield of chisel plowing when compared to minimum tillage.

From the yield results of both maize and sorghum it seems that sorghum is a hardier crop and less affected by tillage. On the other hand maize is a sensitive crop when compared to sorghum.

Table 2. Effect of tillage on establishment and yield.

Treatment	Plant Density '000'plants/ha		Yield kg/ha	
	Sorghum	Maize	Sorghum	Maize
Minimum Tillage	49.29	32.19	1 1567	1808.8
Disc Harrow (DH)	51.67	36.64	1688	2515.7
Heavy Disc Harrow	44.53	36.02	1473	2470.4
Chisel Plow	47.38	35.63	1 1500	2796.5
Disc Plow + DH + Levelling	42.86	32.19	9 969	2380.0
S.E. ±	1.77	1.952	1 196.2	194.2

CONCLUSIONS:

1. Minimum tillage resulted in highest number of weeds and the highest percent groúnd cover for both sorghum and maize.
2. With minimum tillage less water was stored in the 0-30 cm layer and more water was taken than with the other tillage treatments.
3. No differences were observed regarding consumptive water use of sorghum between minimum tillage and other treatments.
4. Consumptive use of water of maize was lower with minimum tillage.
5. Sorghum yield obtained with minimum tillage was not significantly different from other treatments.
6. Maize yield with minimum tillage was significantly lower than other tillage treatments.

EFFECT OF SOIL PREPARATION METHOD AND COTTON-BASED CROPPING SYSTEM ON SEEDBED SOIL PROPERTIES IN A VERTISOL

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ABSTRACT

The effects of soil preparation methods and cotton-based cropping systems on seedbed soil properties were evaluated during the the summer of 1992-1993 in a trial established since 1985 in a Typic pellustert (Vertisol) of North-western New South Wales, Australia. The experimental treatments were maximum tillage (disc-ploughing to 0.2 m depth, chisel ploughing to 0.3 m depth followed by ridging every year) sown to a continuous cotton (*Gossypium hirsutum* L.) sequence; minimum tillage (planting on ridges retained intact from previous years with soil disturbance being limited to deepening of the furrows with disc-hillers) sown to a continuous cotton sequence; and minimum tillage sown to a winter wheat (*Triticum aestivum* L.)-cotton sequence where wheat was sown with no-tillage. Soil was sampled from the 0-0.10 m depth of ridges 4 weeks after sowing (November 1992) and 1 week after harvesting (April 1993) of cotton. Soil properties evaluated were particulate organic matter, particle size distribution, dispersion index, soil reactivity (a measure of the self-mulching ability of the soil), plastic limit, variation of soil density with water content (soil shrinkage), exchangeable Ca, Mg, K and Na, and soil respiration. In comparison with maximum tillage, minimum tillage resulted in lower clay and higher sand contents, lower exchangeable Ca and Na, higher exchangeable K, lower dispersion index, higher particulate organic matter content and lower soil density at water contents < 7.5%. Soil respiration was greatest in minimum tilled plots sown to continuous cotton. Cotton lint yield and fibre quality were unaffected by tillage system but were improved by sowing a wheat-cotton rotation. Lint yield and fibre quality were related to levels of particulate organic matter, exchangeable Na and soil respiration.

INTRODUCTION

Minimum tillage has become a feature of many farming systems, including cotton (*Gossypium hirsutum* L.)-based farming systems, in eastern Australian Vertisols over the past decade (3,6,9,19). Benfits of minimum tillage systems are claimed to include reduction of soil erosion and physical, chemical and biological degradation; improved energy conservation and timeliness of land preparation; and improved water conservation (3,5,9,11,14,19). In cotton-based farming systems minimum tillage is frequently associated with planting crops such as wheat (*Triticum aestivum* L.) in rotation with cotton (6). Most previous studies have addressed the short-term (≤ 3 years) effects and interactions of utilizing minimum tillage systems in combination with crop rotations (3,5). This report presents data on seedbed soil properties from a trial established since 1985 which studied the interactive effects of minimum and intensive tillage systems sown to either continuous cotton or a wheat-cotton rotation on soil properties, and cotton growth and yield (5).

MATERIALS AND METHODS

The trial was located at the Narrabri Agricultural Research Station (annual rainfall of 616 mm) in northern New South Wales, Australia. The soil at the experimental site was a classified as a fine, thermic, montmorillonitic, Typic Pellustert (21). The experimental treatments were maximum tillage (disc-ploughing to 0.2 m depth, chisel ploughing to 0.3 m depth followed by ridging every year) sown to a continuous cotton (*Gossypium hirsutum* L.) sequence; minimum tillage (planting on ridges retained intact from previous years with soil disturbance being limited to deepening of the furrows with disc-hillers) sown to a continuous cotton sequence; and minimum tillage sown to a winter wheat (*Triticum aestivum* L.)-cotton seqnence where wheat was sown with no-tillage. The experimental design was a randomized complete block with 4 replications (8). Individual plots consisted of 36 rows (ridges), 175 m long, spaced at 1 m intervals. Irrigation was by furrow irrigation. Soil was sampled from 28 locations in each plot using a stratified random sampling design (22) from the 0-0.10 m depth of ridges 4 weeks after sowing (November 1992) and 1 week after harvesting (April 1993) of cotton and taken to the laboratory for further analyses.

Air-dried soil was passed through a sieve with 2 mm diameter apertures and particle size distribution determined with the hydrometer method (13), plastic limit with the drop-cone penetrometer (4), particulate soil organic matter (range of 53-2000 µm) with a combination of dispersion, flotation and sieving (7) and dispersion index (20). Total organic carbon was determined by the method of Walkley and Black (18). Soil respiration (during a 2 day period) at 30% soil water content was measured hy trapping the CO_2 produced in a 1M NaOH solution and monitoring the change in electrical condnctivity of the NaOH solution (17). Soil reactivity, a measure of the self-mulching ability of the soil, was determined by puddling and oven-drying at 40 °C for 72 h a sample of air-dried soil which had been previously passed through a sieve with aperture diameters of 2 mm. The size distribution of the aggregates formed (determined by dry-sieving on a mechanical shaker at 1440 vibrations per minute for 5 minutes) was expressed as the geometric mean diameter of the soil aggregates (12). Soil density was measured at soil water contents ranging from 35% to oven-dried value (0%) on drying soil aggregates (1-10 mm diameter), previously wetted by evaporation in a humidifier, with the kerosene saturation method of McIntyre and Stirk (15). 1M ammonium acetate-extractable exchangeable Ca, Mg, K, and Na were determined on air-dried soil sampled in November 1992 and which had been passed through a sieve with aperture diameters of 2 mm (18). After harvest, cotton lint fibre characteristics such as micronaire and length were measured with a Spinlab 900 series, and maturity and fineness with a Shirley FMT3 (13). Data were analyzed following a randomized complete block design for multiple times of sampling (16). One-way analyses of variance were also carried out after grouping of the data according to tillage system and cropping system.

RESULTS AND DISCUSSION

In comparison with maximum tillage, minimum tillage resulted in lower clay and higher sand contents, lower exchangeable Ca and Na, higher exchangeable K, lower dispersion index, higher particulate soil organic matter and lower soil density at water contents < 7.5% (Table 1, Figure 1). Total organic matter did not differ significantly between treatments or times of sampling. Mean total organic matter content in the 0-0.10 m depth was 1.62%. The higher particulate organic matter in minimum tilled plots may be a reflection of the intensity of soil disturbance in these plots (2). The higher clay content with maximum tillage may be due to clay lost with runoff being replaced by sub-surface clay brought to the surface by the intensive tillage in these plots (11), whereas clay losses in minimum tilled plots would not be similarly replaced. Seedbed clay content (%), in turn, was related to some of the soil parameters measured such as exchangeable cations (in mmol(+) kg^{-1}) and soil reactivity (GMD in mm) thus:

$GMD = 0.06Clay - 2.54$, $r = 0.55$, $P < 0.01$, $n = 24$;
Exch. $Ca = 18.46 + 1.21Clay$, $r = 0.67$, $P < 0.05$, $n = 12$;
Exch. $Mg = 1.29Clay - 25.07$, $r = 0.77$, $P < 0.01$, $n = 12$;
Exch. $Na = 0.48Clay - 19.56$, $r = 0.79$, $P < 0.01$, $n = 12$;
Exch. $K = 35.70 - 0.32Clay$, $r = -0.61$, $P < 0.05$, $n = 12$.

Soil structural indices such as dispersion index (DI, %) and soil aggregate density at water contents of 0% (D_0, Mg m^{-3}) and 5% (D_5, Mg m^{-3}) were, however, related to either the combination of particulate organic matter (POM, %) and exchangeable Na or particulate organic matter alone thus:

$DI = 5.07 - 1.32POM + 0.49Na$, $R^2 = 0.58$, $P < 0.05$, $n = 12$;
$D_0 = 1.68 - 0.28POM$, $r = -0.69$, $P < 0.001$, $n = 24$;
$D_5 = 1.49 - 0.16POM$, $r = -0.47$, $P < 0.05$, $n = 24$.

Table 1. Effect of land preparation method and cropping system on soil properties

Land preparation method	Cropping system	Particulate organic matter (%)	Dispersion index (%)	Plastic limit (%)	Sand (%)	Silt (%)	Clay (%)	GMD (mm)	Exchangeable cations (mmol (+)/kg) Ca	Mg	Na	K
Maximum tillage	Cotton-cotton	0.57 (4.041)	11.1	27.4	21.3	18.1	60.6	0.8	92.3	52.1	10.3	16.1
Minimum tillage	Cotton-cotton	1.02 (4.621)	7.6	24.3	26.2	18.6	55.3	0.5	83.6	45.8	6.8	19.4
Minimum tillage	Wheat-cotton	0.92 (4.518)	7.6	23.9	24.7	19.1	56.2	0.5	85.8	47.8	6.7	17.4
AOV:												
Land preparation methods		(**)	***	*	**	NS	***	*	*	NS	***	*
Cropping systems		(NS)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
All treatments		(**)	***	**	*	NS	**	NS	NS	NS	**	*
±SE:												
Between land preparation methods		(0.0801)	0.51	0.68	0.74	0.46	0.71	0.07	1.80	1.68	0.62	0.52
Between cropping systems		(0.0801)	0.51	0.68	0.74	0.46	0.71	0.07	1.80	1.68	0.62	0.52
Between all treatments		(0.0957)	0.46	0.68	1.04	0.48	1.01	0.12	2.96	2.09	0.50	0.63

1. Values in parantheses are $\log_e$ transformed values of 100 x particulate organic matter.
2. GMD = geometric mean diameter of soil aggregates after puddling and drying.
3. Exchangeable cations were determined only on samples obtained in October 1992.
4. NS = non-significant; * = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$.

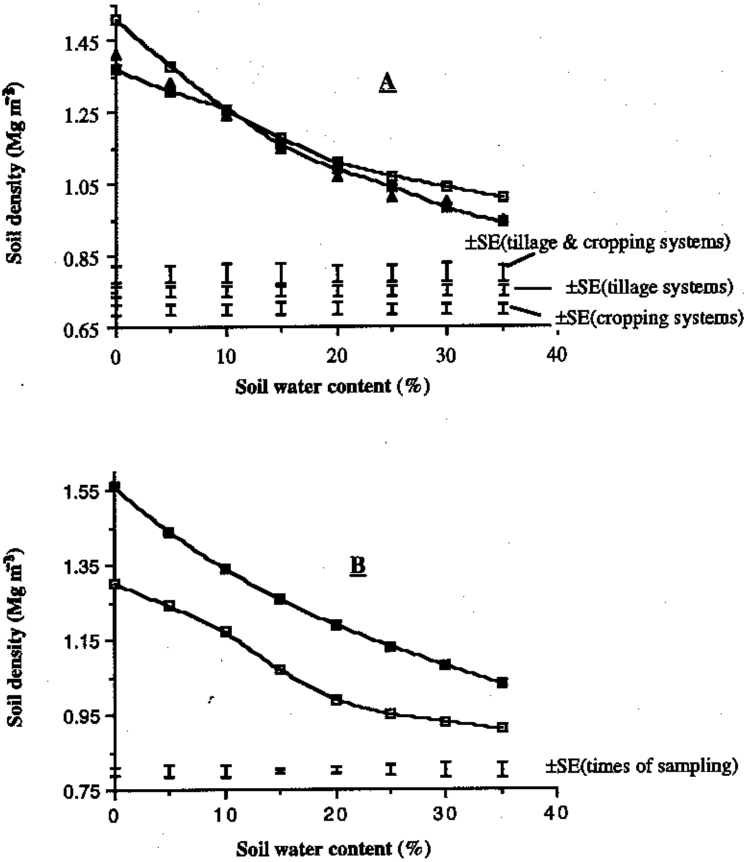

Figure 1. Variation of soil densityin the 0-0.10 m depth with soil water content. A. Effect of tillage and cropping systems. □- Maximum tillage/continuous cotton; ■- Minimum tillage/continuous cotton; ▲- Minimum tillage/wheat-cotton. B. Effect of time of sampling. □- November 1992; ■ - April 1993.

Between November 1992 and April 1993 decreases in particulate organic matter (from 0.97% to 0.68%, $P < 0.05$) and increases in dispersion index (from 7.5% to 10.0%, $P < 0.05$) occurred in all treatments, although significant interactions did not occur between experimental treatments and times of sampling. Similar seasonal changes in particulate organic matter and aggregate stability were reported by Angers *et al.*. (2) for a site in Canada.

Cropping system had no significant effect on the measured soil physical and chemical properties. Compared with continuous cotton, however, soil respiration was less, cotton lint yield higher and fibre quality better where a wheat-cotton sequence was sown (Tables 2 and 3). Cotton lint yield (in t ha^{-1}) and fibre quality were related primarily to soil respiration (R, mmol CO_2/kg soil/48 h), and to exchangeable Na and particulate organic matter to a lesser extent thus:

$Yield = 2.07 + 0.11 \ln POM - 2.95E\text{-}02R - 3.25E\text{-}02Na,\ R^2 = 0.75,\ P < 0.01,\ n = 12;$
$Maturity = 0.85 + 1.06E\text{-}02Na + 9.04E\text{-}03R,\ R^2 = 0.51,\ P < 0.05,\ n = 12;$
$Fineness = 118.27 + 2.57Na + 1.32R,\ R^2 = 0.49,\ P < 0.05,\ n = 12;$
$Length = 1.33 - 0.10POM + 0.13 \ln POM,\ R^2 = 0.71,\ P < 0.01,\ n = 12;$
$Micronaire = 3.01 + 7.67E\text{-}02Na + 4.84E\text{-}02R,\ R^2 = 0.52,\ P < 0.05,\ n = 12.$

The higher soil respiration with continuous cotton may be due to a disease-causing microbial factor which was able to over-winter in the cotton residues and exert a negative effect on cotton lint yield and fibre quality in the following cropping season (1).

Table 2. Effect of land preparation method and cropping system, and time of sampling on soil respiration (in mmol CO_2/kg soil/48 h)

Land preparation method	Cropping system	Time of sampling November '92	Time of sampling April '93	Mean
Maximum tillage	Cotton-cotton	2.7 (1.008)	134.0 (4.898)	19.2 (2.953)
Minimum tillage	Cotton-cotton	7.4 (2.004)	129.7 (4.865)	31.0 (3.435)
Minimum tillage	Wheat-cotton	2.6 (0.957)	130.5 (4.871)	18.4 (2.914)
Mean		3.8 (1.323)	131.4 (4.878)	

	AOV:	±SE:
Times of sampling	***	(0.2135)
Tillage and cropping systems	*	(0.1313)
Times of sampling x tillage and cropping systems	*	(0.1857)

1. Values in parantheses are $\log_e$ transformed values of soil respiration.
2. NS = non-significant; * = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$.

Table 3. Effect of land preparation method and cropping system on cotton lint yield and fibre quality

Land preparation method	Cropping system	Lint yield ($t\ ha^{-1}$)	Maturity	Fineness ($mg\ m^{-1}$)	Length (in")	Micronaire ($\mu g\ in"^{-1}$)
Maximum tillage	Cotton-cotton	1.55	0.99	150.5	1.21	3.95
Minimum tillage	Cotton-cotton	1.64	1.02	152.5	1.22	4.10
Minimum tillage	Wheat-cotton	1.80	0.93	135.8	1.24	3.53
AOV:						
Land preparation methods		NS	NS	NS	NS	NS
Cropping systems		*	**	***	*	***
All treatments		*	***	**	NS	***
±SE:						
Between land preparation methods		0.050	0.010	2.49	0.004	0.081
Between cropping systems		0.050	0.010	2.49	0.004	0.081
Between all treatments		0.053	0.009	2.09	0.006	0.034

1. NS = non-significant; * = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$.

CONCLUSIONS

In comparison with maximum tillage, minimum tillage resulted in significantly better seedbed soil physical and chemical properties. These differences in soil properties did not, however, have a significant effect on crop yield. Cotton lint yield and quality of fibres were best in plots where a wheat-cotton sequence was sown in combination with minimum tillage. The major factors determining cotton yield and fibre quality were soil respiration at the commencement of the cropping season, exchangeable Na and particulate organic matter.

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HYDROLOGICAL PROPERTIES OF A CONVENTIONALLY PLOUGHED TROPICAL ULTISOL AS INFLUENCED BY METHODS OF MULCH APPLICATION*

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ABSTRACT

Changes in soil hydrological properties and bulk density in relation to methods of mulch application were studied for an Ultisol (Oxic Paleudult) in southeastern Nigeria. Mulch was applied at a rate of 24 t ha^{-1} (25% moisture content) of eupatorium (Eupatorium odorantum) straw as two equal split applications at planting and 150 days after planting (DAP). Treatments were complete surface mulching (CSM), mulch incorporated in the top 20 cm layer of the soil (MI), plant row zone mulching (RZM), and an unmulched control (UM). All plots were conventionally plowed and harrowed.

The RZM treatment improved soil bulk density, saturated hydraulic conductivity (K), water infiltration, and soil moisture retention more than other treatments. The RZM treatment decreased the row zone soil bulk denisty in the 0-10 cm depth by 17, 10 and 8 percent under cassava (Manihot esculenta), yam (Dioscorea rotundata) and cocoyam (Xanthosoma sagittifolium), respectively compared with the unmulched control. In addition, loosening of the surface layer of the soil by development of cassava tubers may have partly resulted in the lower bulk density measured under cassava than under yam and cocoyam. Differences in the inter-row bulk density between the CSM, MI and UM treatments were not significant under any crop. The inter-row bulk density under cassava was lower for the RZM treatment than those of CSM, MI and UM treatment by 9, 9 and 6 percent, respectively. Significant differences in K were observed among different methods of mulch application. High values of K were associated with surface application of mulch, either as row zone or complete surface application, than incorporation into the soil or unmulched treatment. Cumulative infiltration (I) after 3 hours in all plots was also the highest for the RZM treatment. At the 0-15 cm depths, the RZM treatment had the highest soil moisture contents, while the UM treatment had the least. Soil moisture suction was the highest (most negative) for the UM treatment and the least for the RZM treatment. The recharge of the soil profile following a rain was complete for the RZM and CSM treatments hut not for the MI and UM treatments.

INTRODUCTION

Soil management practices such as residue management aimed at improving the soil environment for crop growth are necessary for intensive and sustained crop production.

* Contribution from the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria

Efficient management of rains and effective utilization of soil water through improvement in soil's physical and hydrological properties are major goals in residue management practices (Lal, 1975; Ehlers et al., 1980; Ojeniyi, 1986; Maurya, 1986; Roth et al., 1988). Research data on the influence of method of application of a well-defined quantity of plant residue mulch on soil properties and crop yield in the tropics are scanty, and often contradictory. For example, on an Ultisol in Peru, Wade and Sanchez (1983) reported that incorporation rather than surface application of residue resulted in more improvements in soil in more beneficial to soil properties and crop growth. Lal (1978) further observed that placement of mulch between the plant rows or as a uniform surface application was more beneficial to the crop than was concentration of mulch in the plant row. In India, placement of mulch in between the crop rows significantly increased the mean moisture status of the 15 cm soil depth by 1.4 % on a dry weight basis (Gupta and Gupta, 1986). However, Bhatnager et al. (1983) reported no significant difference in soil water content preceding and following irrigation among three residue management treatments as surface application, incorporation, or combination of two. These apparent contradictions may be attributed to differences in antecedent soil properties, prevalent climate, and the time of measuring soil properties in relation to tbe time of mulch application.

With regards to mulch farming in the tropics, there are two critical factors to be considered. Firstly, the availability of mulch material is an important consideration. The logistics of procuring mulch materials in sufficient quantity may limit its use in small holder production systems (Hahn et al., 1979; Opara-Nadi and Lal, 1987). Not only should the mulch material be easily available, it must also have little alternate uses. Eupatorium (Eupatorium odorantum or Chromolaena odorata L.) is a serious weed throughout West Africa. It colonizes fallow land, produces a high biomass over a short period of time, and is not palatable to cattle. In some eco-regions, its residue is easily available for use as mulch throughout the year, and is, therefore, a feasible source of mulch. Secondly, mulch persistence and the duration it stays on the ground as a protective cover are also important consideration. The decomposition rate of mulch, especially the one with a low C: N ration, is generally high in warm humid climates (Jenkinson and Ayanaba, 1977). Split application, therefore, may be necessary to ensure mulch cover throughout the growing season.

The objective of this study was to evaluate the effects of different methods of application of eupatorium mulch on soil moisture content and physical properties of an Ultisol in southeastern Nigeria. Specific measurements were made with regards to the effects of methods of mulch application on soil moisture regime, saturated hydraulic conductivity, infiltration characteristics, and soil bulk density.

MATERIALS AND METHODS

Field experiments were conducted on an Ultisol (a typic Paleudult) at Onne, a suhstation of International Institute of Tropical Agriculture (IITA) located in the high rainfall region of southeastern Nigeria. Experiments were conducted for two consecutive seasons e.g. the 1983/84 and 1984/85 growing seasons. The physical and chemical properties of the soil and some important characteristics of the experimental site are reported in details elsewhere (Maduakor et al. 1984; Opara-Nadi and Lal, 1987).

The experimental design was a complete randomized block with three replications. Each replicate consisted of four plots, each measuring 11 x 5 m in area. Treatments were four methods of mulch application as follows: Treatment 1: complete surface mulching (CSM); Treatment 2: mulch incorporated in the entire plot (MI); Treatment 3: surface mulching in the row zone only (RZM), (with mulch applied approximately 25 cm on either side of planting row); and Treatment 4: unmulched control (UM). All plots were disc-plowed to a depth of approximately 20 cm and harrowed before applying mulch. Mulch was applied at the rate of 12 t ha^{-1} fresh eupatorium straw (25% moisture content) 2 days before planting. A second application of 12 t ha^{-1} was made at 150 days after planting (DAP) because of the high rate of mulch decay resulting in disappearance of the mulch cover. For treatment 2, the mulch was incorporated with the harrowing and complete incorporation was achieved with hand hoes. Time of mulch application was not a treatment variable. Weed control in all plots was achieved by spraying with a mixture of paraquat (1-1', dimethyl 4,4' bypyridilium ion) at 2.5 ha^{-1} and fluometuron [1, 1-dimethl-3-($\propto$,$\propto$,$\propto$-trifluorom-tolyl)] at 5.1 ha^{-1}. Subsequent weed control, as and when needed, was achieved by hand weeding.

Planting

Details of planting, soil and plant sampling techniques have been reported in an earlier paper (Opara-Nadi and Lal, 1987). Cassava cuttings were planted on the flat on 14 April, 1983 and 2 May, 1984. Yam sets were planted on 16 April, 1983. During the 1984 planting season, yam was replaced with cocoyam and planted on 2 May, 1984. Plant spacings of 1 m between and 1 m within rows were used for all crops. Each crop was planted as a sole crop. Fertilizer was not applied during the experiment.

Observations

Soil bulk density in the 0-10 cm depth, in the row and inter-row zones, was measured on undisturbed cores (5 cm long and 5 cm internal diameter). Three cores were taken within and another three cores between plant rows, giving a toal of six cores per plot. Core samples were taken at random from each plot, but at approximately 50 cm from the plant for both row and inter-row sampling. The samples, obtained one week before harvesting in each year, were also used for measuring saturated hydraulic conductivity (K) using a constant head permeameter.

Infiltration was measured in the row with a double-ring infiltrometer. Measurements were made on two plots of each treatment. Tensiometric measurements of soil-water suction within the plant row in the cassava plot were made at the 20 cm depth using suction gauge tensiometers during the 1983/84 growing season. One tensiometer was installed in each plot of each treatment. Soil moisture contents in the 0-15, 15-45 and 65-95 cm depths were determined gravimetrically for the cassava and cocoyam plots during 1983-84 season respectively. Soil moisture samples were obtained from one location in each plot. Gravimetric moisture content was converted into volumetric moisture content using the corresponding bulk density of each depth.

RESULTS AND DISCUSSION

Soil properties

Bulk density

Mulching treatments had significant effects on both row and inter-row bulk density under cassava in 1983. In 1984, however, inter-row bulk density under cassava did not differ among treatments. Under yam and cocoyam also, treatment effects were significant for the row bulk density only (Table 1). The RZM treatment decreased the row bulk density by 17%, 13%, 10% and 8% in the cassava-1983, cassava-1994, yam and cocoyam plots, respectively, compared with the unmulched control. Low bulk density in the row zone of RZM treatment is due to several factors. Large quantiy of mulch was concentrated in the narrow zone (50 cm rater than 1 m wide strip). The thick layer of mulch prevented rain drop impact, and may have stimulated activity of soil fauna (earthworms and termites) more than in the CSM or MI treatments. If the quantity of mulch applied were doubled in CSM treatment, its bulk density in the row zone may have been equivalent to that of RZM. Loosening of the surface layer of the soil by development of tuhers may also have partly contributed to the lower bulk density, more so in bulky cassava tubers than in other crops. However, differences in the row bulk density between the CSM, MI and UM treatments were not significant under any crop. The inter-row bulk density under cassava in 1983 for the RZM treatment was lower than those of the CSM, MI and UM treatment by 9%, 9% and 6% respectively. The bulk density of the CSM, MI and UM cassava treatments measured in the inter-row zone was not significantly different among treatments.

Table 1. Effect of methods of mulch application on bulk density of 0-10 cm depth.

Treatment[1]	Cassava				Yam 1993		Cocoyam 1984	
	1983		1984					
	R[3]	I	R	I	R	I	R	I
CSM	1.33a[2]	1.39a	1.35a	1.41a	1.32a	1.34a	1.37a	1.33a
MI	1.36a	1.33b	1.39a	1.33a	1.34a	1.35a	1.33a	1.33a
RZM	1.15b	1.27b	1.20b	1.38a	1.23b	1.32a	1.22b	1.38a
UM	1.38a	1.39a	1.38a	1.40a	1.36a	1.35a	1.32a	1.35a

1. CSM = Complete Surface Mulching; MI = Mulch Incorporated; RZM = Row Mulching; UM = Unmulched Control.
2. Means followed by the same letter in the collumn are not significantly different at the 5% level of Duncan's new multiple range test.
3. R = row; I = inter-row.

Saturated hydraulic conductivity (K)

Significant differences in K occurred among different methods of mulch application (Table 2). Differences among treatments were more pronounced in the row than in the inter-row zone. Value of K in the row zone was the highest for the RZM treatment compared with other treatments is in accord with the low bulk density for the RZM treatment (Table 1). On the other hand, K in the inter-row zone was highest for the CSM treatment and least for the MI treatment. Preventive effect of mulch in the CSM against raindrop impact is likely to be a causative factor for high K in the inter-row zone. High K in the row zone than in the inter-row zone is also in accord with low bulk density values in the row zone due partly to the heaving effect of tuber development and thick layer of mulch.

Table 2. Saturated hydraublic conductivity (K) in the 0-10 cm depth as affected by method of mulch application.

Treatment[1]	Cassava (1983)		Yam (1983)		Cocoyam (1984)	
	R[3]	I	R	I	R	I
CSM	121b[2]	95a	109bc	112a	139ab	122a
MI	73b	52b	52c	47b	61c	57a
RZM	209a	84a	184a	102a	194a	145a
UM	115b	69a	125	96a	129bc	119ab

1. Abbreviations as Table 1.
2. Means followed by the same letter in the column are not significantly different at the 5% level of Duncan's new multiple test.
3. R = row; I = inter-row.

Water infiltration

Cumulative infiltration (I) after 3 hours for different methods of mulch application is shown in Table 3. Cumulative infiltration was highest for the RZM treatment in all plots and the lowest for the MI treatment. The high value of I for the RZM treatment may be attributed to the low soil bulk density, high porosity, and lack of crust formation because of the concentration of mulch in the row zone. On the other hand, the euaporium mulch layer beneath the soil surface may have been created hydrophobicity by changing the contact angle between soil and water, thus resulting in low I for the MI treatment (Opara-Nadi and Lal, 1987).

Table 3. Effect of methods of mulch application on cumulative infiltration (I) after 3 hours during 1983 and 1984.

Treatment[1]	Cassava		Yam 1983	Cocoyam 1984
CSM	172b[2]	213b	99b	80b
MI	77c	187b	54b	118b
RZM	248a	326a	330a	320a
UM	212b	209b	86b	139b

1. Abbreviations as Table 1.
2. Means followed by the same letter in the column are not significantly different at the 5% level of Duncan's new multiple test.

Fluctuations in soil-moisture suction at 20 cm depth for cassava plots during the 1983/84 growing season are shown in Fig. 1. Soil moisture suction was highest (most negative) in the row zone for the UM treatment and least (less negative) for the RZM treatment. Moisture suction for the CSM and MI treatments was inbetween. These trends in soil moisture suction may be due to high evaporation and more runoff losses in UM compared with other treatments. Furthermore, the recharge of soil moisture from 238th to the 249th DAP following two heavy rains on December 10 and 17, 1983, was in the order of RZM>CSM>MI>UM. Once again, high losses due to surface runoff and evaporation in MI and UM treatments would lead to low soil water recharge compared with RZM and CSM treatments.

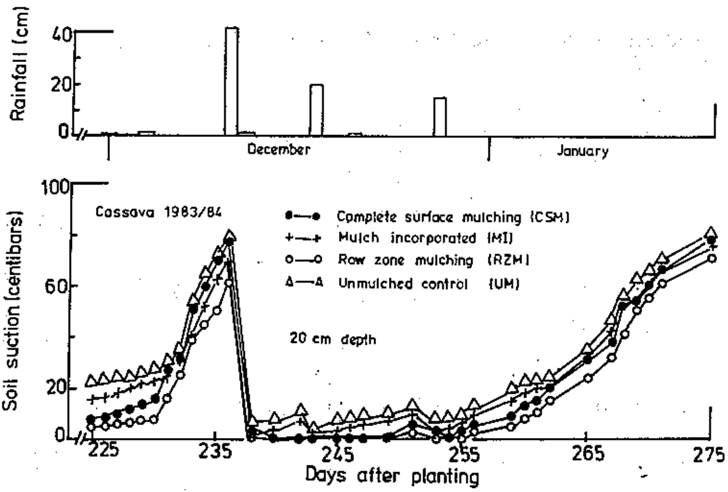

Fig. 1. Soil moisture suction at the 20 cm depth under cassava as influenced by method of mulch application and rainfall events.

Soil moistrue content

Soil moisture content in the 0-15, 15-45 and 65-95 cm depths under cassava are shown in Fig. 2. Soil moisture content is an integrated response of mulch/crop growth effects on infiltration, runoff, evaporation, and soil-water storage. The quantity and spatial distribution of mulch affects all these parameters. Soil moisture content was lowest for the UM treatment, but similar for the RZM, CSM and MI treatments. Trends in moisture content in 0-15 cm depth under cocoyam were similar to that of cassava (date snot shown).

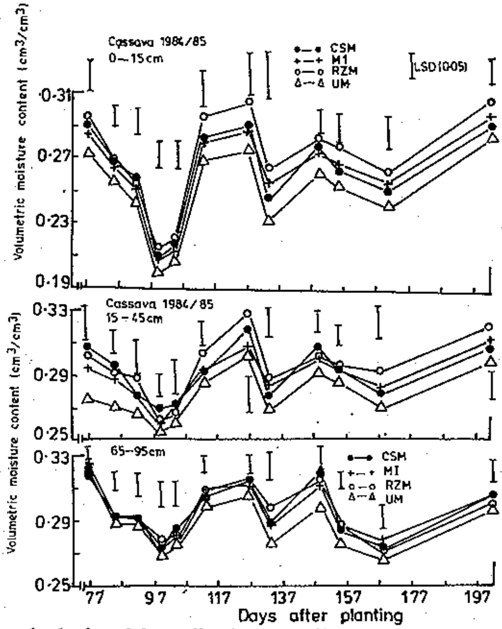

Fig. 2. Effect of method of mulch application on soil moisture content under cassava.

CONCLUSIONS

1. Mulching in the row zone was associated with more favorable soil bulk density, K, I, and soil moisture content than other treatments.

2. Mulcb application significantly decreased row and inter-row bulk density under cassava, and the row bulk density under yam and cocoyam.

3. Surface application of mulch caused more improvement in K than incorporation of mulch into the soil.

4. Cumulative infiltration was lowest for the mulch incorporated treatment.

5. Soil moisture suction in the row zone was the highest for the unmulched treatment and the least for the RZM treatment. Soil moisture content, on the other hand, was the least for the unmulched treatment and highest for the row zone mulching treatment.

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THE COMPARATIVE RESPONSE OF COWPEA AND MAIZE TO CONVENTIONAL TILLAGE AND NO-TILLAGE ON CLAY AND LOAM SOILS

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ABSTRACT

Field studies were conducted on a heavy clay soil (77% clay, 22% silt), a lighter clay soil (40% clay, 19% silt) and a loam soil (24% clay, 42% silt) in Guyana and Trinidad, to determine the growth and yield of maize and cowpea under conventional tillage and no-tillage. In Guyana there is a mild wet season from December to January and an intense wet season from May to July or August, while in Trinidad there is one prolonged wet season with a major peak in June–August and minor peak in October–November. On the heavy clay soil, no-till significantly reduced germination of maize on 6 m wide beds compared to tillage but not on 3 m wide beds. This resulted in significantly lower cob yield per hectare on 6 m no-till plots. On the 3 m wide beds however maize yield was significantly higher under no-till. Germination on this soil type was higher in the major wet season than in the minor wet season, but grain yield was higher in the minor wet season. For cowpea, no-till increased several plant parameters including yield in the major wet season but differences between till and no-till were generally not significant. On the lighter clay soil, no-till did not significantly reduce cowpea vegetative plant parameters and yield on 6 m wide beds compared to the tilled plots. However, cob yields were significantly decreased by minimum and no-tillage on 9 m wide beds particularly during heavy rainfall conditions. Plant parameters were higher on the loam soil with or without tillage. However maize and cowpea can be grown on clay soils without tillage and with or without mulch provided drainage is adequate. The optimum bed width would depend on soil type and rainfall.

INTRODUCTION

Tillage has been defined as the mechanical manipulation of the soil to provide soil conditions suited to the growth of crops, the control of weeds and for the maintenance of infiltration capacity and aeration (1). There has been some concern of the suitability of conventional tillage to the harsh tropical climate (2, 3, 4). In light of these reappraisals much interest has been shown in reduced tillage and no-tillage methods (2, 3). Researchers have also suggested the need to prescribe tillage practices on the basis of soil, climate, crop and socio-economic considerations (5, 6). Soil texture, moisture content, slope, and erosion hazard are among the important soil factors.

No-tillage and conservation-tillage have initially been developed on the lighter textured soils and have been found useful on sloping lands, and soils prone to erosion and drought stress (7). Reports in the literature have indicated that there is very little difference in crop response to variations in tillage implement combinations (8, 9). There have also been mixed responses of crops to conventional versus reduced tillage systems (5, 7). These discrepancies are expected in view of the variations in the initial soil conditions, crop species, soil fertility status, climate and soil tillage implement interactions (10). A strong drainage-tillage interaction has been reported (3), so unless drainage is managed tillage systems will have limited or no effect on plant growth and soil properties.

Several researchers have suggested the unsuitability of no-tillage to soils with impeded drainage (11, 12 13). However, no-tillage may be necessary on these soils in the wet season when the soils cannot be readily trafficked or tilled provided raised beds are used to facilitate drainage, or no-tillage may be beneficial during the dry season. The use of heavy equipment and continuous tillage at the same depth may lead to the development of compacted or indurated layers (14). This may be more marked on the fine textured clay soils.

Guyana is located on the northern coast of the continent of South America (1°10′–8°32′ N latitude and 56°30′–61°20′ W longitude. The Atlantic coastline of Guyana is 440 km long, is recent in origin and has been formed by deposits of suspended material borne by the numerous rivers within Guyana, and by the Amazon river. A part of the coastal strip has been recovered from the Atlantic ocean by the construction of dykes and therefore lies below sea level at high tide. The agriculturally important part of the coastal plain is therefore marine and riverain clay soils. These soils are poorly structured, and prone to flooding, crusting and compaction. The coastal strip occupies about 8.5% of the land area of Guyana (15) but supports about 90% of the population. The coastal plain is therefore economically very important. The clay soils of the island of Trinidad are formed from sedimentary materials as the land rose from the sea, and from alluvium in the flood plains of the rivers.

These clay soils in Guyana and Trinidad are poorly structured, and prone to crusting and compaction. This causes poor aeration and mechanical impedance to root growth. In addition, high rainfall and the flat low lying topography aggravates the inherent poor aeration of the soil, and waterlogging is prevalent. It is therefore not surprising that the main agricultural crops are sugar cane (*Saccharum officinarum* L.) and rice (*Oryza sativa* L.). Rice is grown under flood conditions. Sugar cane is a long duration, hardy crop, is able to survive the adverse conditions and grows under the more favourable periods during the year. These crops have been grown successfully for many decades. A diversification program was initiated in the 1970's with the main policy objectives of import substitution and risk reduction. Maize (*Zea mays*) and cowpea (*Vigna unguiculata* L. Walp) were two crops targeted for expanded production. However, the traditional system of soil physical management which has been used for sugar cane production resulted in large variations in crop growth and yields of maize and cowpea.

This study was therefore undertaken to compare the production of maize and cowpea on clay and loam soils under conventional tillage and no-tillage under the climatic conditions of Guyana and Trinidad and to propose appropriate soil and crop management system for the environmental conditions.

MATERIALS AND METHODS

Experimental sites

The trials were conducted in Guyana, South America at the Central Agricultural Station, Mon Repos (7°50′ N latitude, 58°40′ W longitude), and in Trinidad, West Indies at the Ministry of Agriculture, El Carmen Research Station an at the University of the West Indies campus (10°30′ N latitude 60°25′ W longitude).

There are two rainy seasons in Guyana, the shorter less intense minor wet season in December–January, an the longer more intense major wet season in May–July which may start in late April and be prolonged into early to mid-August. In Trinidad there is one prolonged wet season, May/June–December with two distinct peaks. The heaviest rains occur in June–August (the major peak) and smaller peak in October–November.

Soil

The soil type of experimental site in Guyana is mapped as Onverwagt clay. This soil type belongs to a family of isohyperthermic fine and very fine mixed non-acid clays in the sub group Aeric Tropaquept (16). The soil contains (in the 0–45 cm depth) 75–80% clay, 20–25% silt and virtually no sand. It has low internal drainage.

Two soil types were used in Trinidad, Cunupia clay and St. Augustine loam. Cunupia clay is classified as an Inceptisol of the fined mixed isohyperthermic family of the subgroup Aquic Eutropepts. It contains 39–40% clay, 18–20% silt and 40–42% sand in the 0–45 cm depth, and has impeded internal drainage. St. Augustine loam is an Ultisol, a kaolinitic member of the isohyperthermic family of the subgroup Orthoxic Tropudult (16). It contains 24% clay, 42% silt and 34% sand in the topsoil.

Planting Material
Cowpea (*Vigna unguiculata* L. Walp) and maize (*Zea mays* L.) were the crops used. The cowpea variety used in both Guyana and Trinidad was California No. 5. The maize variety used in Guyana was CAS 181, a composite of broad genetic based characterized by a relatively short plant and low volume of vegetative matter; while the maize variety used in Trinidad was the hybrid Pionner X304B.

Land preparation
Guyana: Conventional land preparation for both cowpea and maize consisted of disc ploughing to a depth of 20–25 cm, followed by two weeks of weathering then harrowing firstly with a 56 cm disc harrow with two gangs of nine discs each, and secondly with a lighter 48 cm disc harrow with a similar number of gangs and discs. Interbed drains were dug with a drain digger and refined by hand shovel.

Trinidad: Tillage method on the Cunupia soil consisted of disc ploughing to a depth of 20–25 cm followed by two passes with a rototiller. For the St. Augustine loam, tillage consisted of rotatilling to a depth of about 10 cm with a hand tractor (Troy Bilt 7HP).

No-tillage
No-tillage plots were sprayed about two weeks before planting mainly with roundup (glyphosate) isopropylamine salt of N–(phosphonomethyl) glycine. Occasionally paraquat was used. Mixed grass, other weeds and maize stubble were used as mulch where appropriate to a depth of 5 cm or 10 cm.

Experimental layout
All experiments were laid out as a split plot design replicated three times with tillage as main plot and mulch or nitrogen as sub-plots. The results of the sub-plot treatments are not all reported here. The results were analysed for standard error and tested for statistical significance.

Plot size: In Guyana the field was laid out in raised beds and each block consisted of three 110 m × 3 m (or 6 m) beds. In Trinidad the field was also laid out in 3 m wide beds and the main plot was 75 m × 3 m. Main plot lengths were subdivided equally depending on the number of sub-plot treatments.

Planting and fertilization
Both cowpea and maize were planted by hand. Cowpea was planted at a spacing of 50 cm × 20 cm and maize was planted at 75 cm × 20 cm. Three seeds were planted per hole and thinned to one plant per hole 15 days after sowing (DAS). Cowpea was given 80 kg ha^{-1} of triple superphoshpate (TSP) only, while maize received 300 kg ha^{-1} sulphate of ammonia (150 kg ha^{-1} at planting and 150 kg ha^{-1} at 35 DAS), 150 kg ha^{-1} TSP and 100 kg ha^{-1} muriate of potash (MP).

Weed Control
Both pre-emergent and post-emergent herbicides and hand weeding were used to ensure weed free conditions. Several chemicals were used in accordance with the recommendations of the respective Ministries of Agriculture.

Pest and disease control
Several pesticides were used routinely in accordance with the particular pest and the recommendations of the Ministries of Agriculture. The soil was also sprayed to control soil

insects and soil fungi. Fall army worm (*Spodoptera frigiperda*) and leaf miner (*Tiriomyza trifolii*) were two of the pests observed on maize and cowpea respectively. Under high moisture conditions, aphids (*Aphis gossypii*) occurred on cowpea and were controlled with benlate.

Plant growth parameters
Several plant parameters were measured by standard methods. Leaf area was measured on a leaf area metre (Hayashi Danko (AAM-5) Japan)

RESULTS

Maize on Onverwagt clay soil in the major wet season (Guyana)
The germination and yield of maize on Onverwagt clay in the major wet season in Guyana are presented in Table 1. The first maize trial (trial 1) was conducted on 6 m wide beds. The no-tillage plots were mulched with a 10 cm thick grass mulch and the tilled plots were either similarly mulched or unmulched. Germination and subsequent plant population were sigificantly lower ($P = 0.05$) on both the no-till and mulched till plots. This resulted in significantly ($P = 0.05$) lower number of cobs and total cob yield. However, the mean cob weight and the dry weight of individual maize stalks were not significantly affected by the treatment.

Table 1 The effect of tillage on germination and yield of maize on 6 m wide beds on Oneverwagt clay (Guyana).

Plant parameter	No-till +10 cm grass mulch	Till +10 cm grass mulch	Till only	LSD ($P = 0.05$)
Germination (%)	42.3	35.8	89.7	29.2
No. of plants ha^{-1}	29746	30424	45403	10431
No. of cobs ha^{-1}	29744	27960	45402	7768
Cob yield, kg ha^{-1}	2175	2600	4226	1623
Mean cob wt (g)	73.3	86.7	93.3	n.s.
DW of maize stalks (g plant^{-1}) 90 DAP	180.1	180.0	186.7	n.s.

DW is dry weight

The height of stalks along the 6 m wide beds was non-uniform and these were observed to be associated with soil depressions. The micro-relief of the beds was therefore mapped and two trials (trials 2 and 3) run in successive years to measure plant response to high and low elevations. Final stalk height, number of plants per hectare, number of cobs per hectare and grain yield per hectare were therefore measured on replicated no-till and till plots on high and low elevations.

Tillage did not significantly affect any of the parameters measured at either the high or low elevations. Elevation, however, had a significant effect on the yield parameters (Table 2) when rainfall was heavy (977 mm during the crop) in trial 2. The high elevation gave significantly higher ($P = 0.05$) values of all the parameters than low elevation. The low elevation had a reduced plant population and shorter plants, possibly the result of periodic flooding and waterlogging. In the third trial, where the rainfall was not as heavy (584 mm), the low elevation did not have a significant effect on final stalk height, plant population and dry weight yield of cobs (Table 2).

Table 2 Mean yield parameters at high and low elevation for two maize trials on Onverwagt clay (Guyana).

Parameter	Elevation	
	High	Low
Trial 2 (Rainfall 977 mm)		
Final stalk height (cm)	171.0 ± 6.3a	159.1± 2.1b
No. of plants ha^{-1}	49416±6207a	21778±4258b
No. of cobs ha^{-1}	45722±5803a	19027±4154b
Grain yield (kg ha^{-1})	1811± 201a	1004± 365b
Trial 3 (Rainfall 584 mm)		
Final stalk height (cm)	117.2 ± 1.1a	117.2± 1.3a
No. of plants ha^{-1}	24305±5785a	28416±5918a
DW yield of cobs (kg ha^{-1})	1615± 358a	1887± 437b

Parameter means at low and high elevations with the same letters are not significantly different at P = 0.05 according to Duncan's Multiple Range Test.
DW is dry weight

The subsequent maize trial (trial 4) was therefore conducted on 3 m wide beds to minimise soil depressions and improve drainage. The no-till plots were mulched with grass 5 cm and 10 cm thick. Germination on the no-till and till plots was greater than 91% and there was no significant difference between no-till and till plots (Table 3). The no-till plots produced significantly more grain yield per hectare than the till plots but this was due to the larger number of plants and cobs per hectare on no-till plots. More seedlings on till plots did not survive probably because of greater incidence of pests and disease. The total rainfall during trial 3 and trial 4 was 584 mm and 580 mm, respectively. Therefore differences in germination and crop growth between the 6 m and 3 m beds were not caused by differences in rainfall.

Table 3 The effect of tillage on germination and yield of maize on 3 m wide beds on Onverwagt clay (Guyana).

Plant parameter	No-till +10 cm grass mulch	Till +10 cm grass mulch	Till only 3 m wide beds	LSD (P = 0.05)
Germination (%)	92.7	91.8	91.3	n.s.
No. of plants ha^{-1}	57500	54166	48833	n.s.
No. of cobs ha^{-1}	56100	52167	47500	n.s.
Cob yield, kg ha^{-1}	1867.3	1650.7	974.3	187.4

Maize and cowpea on Onverwagt clay in major and minor wet seasons (Guyana)
Plant growth parameters of cowpea and maize in response to tillage of Onverwagt clay in the minor and major seasons were studied. The germination percentages of cowpea (Table 4) and maize (Table 5) were higher in both the minor and major wet seasons (Table 4 and 5). It was also higher in the major wet season than the minor wet season in both crops especially cowpea. Tillage significantly increased germination of maize in the major wet season, and cowpea in the minor wet season on till than on no-till plots. It would appear that tillage provided better soil-seed contact which was particularly beneficial to maize in the major wet

season. The number of cowpea plants per hectare at harvest were positively correlated with the germination percentage.

Table 4 The effect of tillage in the minor and major wet season on maize grown on Onverwagt clay (Guyana).

Plant parameters	Minor Wet season		Major wet season	
	Till	No-till	Till	No-till
Germination (%)	80.0	77.1	94.2**	79.1
Stalk height 78 DAS (cm)	212.4	213.7	213.0	193.8
DW stalk (g plant^{-1})	386.8	354.3	266.2	250.6
Rooting depth (cm)	36.3*	29.7	31.8*	20.9
Grain yield (kg ha^{-1})	2553.6*	1973.0	1186.8*	714.6

DW is dry weight

Table 5 The effect of tillage in the minor and major wet seasons on cowpea grown on Onverwagt clay (Guyana).

Plant parameters	Minor Wet season		Major wet season	
	Till	No-till	Till	No-till
Germination (%)	87.9	81.4	93.2	91.6
No of plants ha^{-1}	76300	65800	79514	78090
DW of tops^{+}	10.20	8.77	21.24	17.32
DW of roots^{+}	3.9	3.3	5.1	6.5
DW of nodules $^{++}$	0.11	0.16	0.81	1.07
No. of nodules plant^{-1}	20	35	110	182
No of pods plant^{-1}	64.6	51.6	51.8	73.1
DW of pods^{+}	62.6	53.8	54.1	70.8
DW of seed^{+}	51.1	41.2	46.9	51.7
Dry seed yield (kg ha^{-1})	389.9	271.1	366.4	412.7

$^{+}$ g plant^{-1}; $^{++}$mg plant^{-1}; DW is dry weight

The stalk heights of maize were not significantly affected by tillage in the minor and major wet seasons but the dry weight of stalk per plant, rooting depth, and yield were higher in the minor wet season and higher for till than no-till. The differences in rooting depth and grain yield were significantly higher on till than no-till plots.

For cowpea most of the parameters were however higher in the major wet season than the minor wet season (Tables 5). While tillage increased most of the plant parameters in the minor wet season, it was the reverse in the major wet season but the differences, and importantly the differences in dry seed yield, were not significant. The higher soil moisture conditions of the no-till plots did not adversely affect cowpea.

Cowpea on Cunupia clay (Trinidad)
The effect of tillage on plant parameters of cowpea on the lighter Cunupia clay in Trinidad is shown in Table 6. The data represent mean value for the crop grown on 6 m wide beds in 1983 and 1984. There were no significant differences in plant height, leaf area, shoot, root and nodule dry weight, seed yield and pod yield of cowpea on till and no-till plots. The results were similar in 1983 and 1984 and were not affected by the higher rainfall and higher mean pan evaporation in 1984 (Table 7).

Table 6 The effect of tillage on growth and yield parameters of cowpea grown on 6 m wide beds of Cunupia clay (Trinidad) in 1983 and 1984

Plant parameter	Till	No-till + mulch	SEM
Plant height (cm) at 42 DAP	34.5	33.9	5.86
Leaf area (cm^2 $plant^{-1}$)	808.2	642.3	112.4
DW of tops (g $plant^{-1}$)	5.87	5.28	0.61
DW of roots (g $plant^{-1}$)	0.62	0.55	0.09
DW of nodules (mg $plant^{-1}$)	92.2	132.8	27.13
Pods $plant^{-1}$	8.3	7.8	0.44
100 seed weight (g)	16.0	16.5	0.36
Dry seed yield (kg ha^{-1})	353.8	384.6	21.1
Yellow pod yield (kg ha^{-1})	1424.0	1533.5	68.2

DW is dry weight

Table 7 Rainfall and pan evaporation (mm during the 1983 and 1984 cowpea trials on Cunupia clay

Year	Rainfall		Pan Evaporation
	Total	Mean daily	Mean daily
1983	525.8	6.6	5.2
1984	635.3	9.1	5.6

Maize on Cunupia clay (Trinidad)
The response of maize to conventional, minimum and zero-tillage (no-till) was studied in two trials on 9 m wide beds of Cunupia clay. The rainfall during the first trial (May–September) was 1094 mm, and it was 837 mm during the second trial (October–January). The high rainfall in the first trial caused prolonged waterlogging on the 9 m wide beds.

Table 8 shows that rooting and cob yield of maize were lower during the first trial when rainfall was high. It also shows that conventional tillage significantly increased root dry weight, root length and cob yield compared to minimum and no-tillage in both trials. Drainage was not very efficient on the 9 m wide beds of this soil type when rainfall was excessive. This had an adverse effect on maize when the soil was not tilled conventionally.

Table 8 The effect of tillage on rooting and fresh cob yield of maize on 9 m wide beds on Cunupia clay (Trinidad)

	Tillage Treatment	Root		Yield
		DW g plant^{-1}	Length cm	t ha^{-1}
First Trial	Conventional	11.4	36	5.64
	Minimum	4.9	24	1.33
	No-till	6.9	26	1.92
LSD (0.05)		3.14	6.1	1.94
Second trial	Conventional	44.6		12.16
	Minimum	34.0		9.39
	No-till	32.5		9.29
LSD (0.05)		8.9		1.81

Cowpea on St. Augustine loam (Trinidad)
The effect of tillage on cowpea plant parameters grown on St. Augustine loam is shown in Table 8. Plant height of cowpea on plots that were tilled was significantly greater ($P = 0.05$) than plant height on unmulched no-till plots. It was however not significantly greater than on no-till plots which were mulched. Tillage did not significantly increase any of the other parameters measured, including seed yield. Total rainfall during the 7 days of the trial was 395.8 mm and pan evaporation was 183.3 mm. The amount of rainfall was adequate to excessive but the soil drained readily. The soil moisture was however, always above 50% of the available range for this soil. Although several intense storm events occurred during the trial prolonged waterlogging was not observed.

Table 9 The effect of tillage on growth and yield parameters of cowpea grown on St. Augustine loam

Plant parameters	Till	No till + mulch	No-till and no mulch	SEM
Plant height (cm) (42 DAP)	111.8	106.3	100.7	3.1
Leaf area	2338.0	4819.8	2265.4	1369.1
Shoot dry weight (g plant^{-1})	17.76	20.42	17.63	1.32
Root dry weight (g plant^{-1})	1.19	1.23	1.12	0.08
Nodule fresh weight (mg plant^{-1})	659.0	696.0	437.0	125.2
Pods plant^{-1}	15.2	13.6	13.9	0.61
100 seed weight (g)	16.2	16.5	16.3	0.20
Dry seed yield (kg ha^{-1})	893.0	795.0	870.0	56.6

DISCUSSION

Clay soils are an important group of agricultural soils which have produced crops commercially and successfully in many parts of the worlds. They however present challenging management problems in the humid tropics. One of the major problems is the difficulty of trafficking and tilling the soils to produce the desired soil structure when the soil moisture content is high. The ability to grow crops successfully without tillage can overcome the problem. No-tillage is conventionally combined with mulch to improve soil structure, reduce raindrop impact, increase infiltration, reduce runoff and reduce soil erosion (2, 7, 13), but mulch on clay soils can present problems of excessive soil moisture and wate, rlogging in the wet season. In these studies no-tillage was not used as a soil conservation measure but to avoid tilling the wet soil so that mulching is not essential and may be a disadvantage.

The bedding system of field layout is necessary for crop production on the clay of Guyana and Trinidad to improve surface drainage and to elevate the soil surface from the perched water table which can be as close as 15 cm from the flat soil surface in the wet season (17). On the heavy Onverwagt clay soil 3 m wide beds had higher germination, plant population and yield than 6 m wide beds. Drainage was poorer on the 6 m wide beds and it was difficult to avoid soil depressions after land forming operations. These depressions caused prolonged local waterlogging which resulted in reduced plant growth and yield. Mulching increased the soil moisture content and decreased germination and yield of maize on the 6 m wide beds but the yield reduction was not statistically significant (Table 1). Mulching however did not reduce the plant parameters as much as soil depressions.

Although the germination of maize was higher in the major wet season than in the minor wet season, the grain yield at harvest was higher in the minor wet season (Table 4). The higher rainfall and consequent higher soil moisture contents (data not presented) reduced rooting depth and stalk weight per plant. Germination of cowpea on the heavy clay soil and most of the plant parameters measured were also higher in the major wet season.

On the heavy Onverwagt clay no-till significantly reduced germination of maize on 6 m wide beds compared to tillage without mulch but not on the 3 m wide beds (Tables 1 and 3). This resulted in significantly lower cob yield per hectare on 6 m no-till plots. On the 3 m wide beds however grain yield of maize was significantly higher under no-till. It would seem that provided drainage is good, no-till can provide higher yields. For cowpea, no-till increased several plant parameters in the major wet season but the differences between no-till and till were generally not significant. It is evident that both maize and cowpea can be grown on this soil type in the major and minor wet season without tillage. Mulching did not adversely affect the crops provided in-field drainage was adequate which was achieved by 3 m wide cambered beds and unobstructed drains between the beds.

On the lighter Cunupia clay soil, no-till + mulch did not significantly reduce cowpea vegetative plant parameters and yield on 6 m wide beds compared to the tilled plots. This soil is more permeable than the Onverwagt clay and the wider 6 m beds exhibited less waterlogging problems. However, when maize was grown on 9 m wide beds, cob yields were significantly decreased by minimum and no-tillage particularly during heavy rainfall conditions. It would appear that the optimum bed width depends on the crop and the rainfall conditions. Since rainfall fluctuates annually it is recommended that bed widths should be kept as small as possible to improve drainage and avoid excessive waterlogging in the event of unusual rainfall intensities.

Plant parameters, including seed yield, were much higher on St. Augustine loam with and without tillage than on Onverwagt and Cunupia clay soils. The loam is obviously the preferred soil for crop production under no-till or till method of land preparation. However cowpea and maize can be grown on clay soils without tillage but it is essential to ensure adequate soil surface drainage. This can be achieved by the use of the appropriate width of cambered beds. An economic assessment is however needed to determine the commercial viability of production on both types of clay soils at the yields attainable.

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COVER CROP NITROGEN AVAILABILITY TO CORN WITH CONSERVATION TILLAGE

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ABSTRACT

Field experiments were established to evaluate the timing of nitrate N release in soil (to various depths) with moldboard plowing (fall vs. spring), no-till (with different timings of chemical kill) and chisel plowing in corn production after cover crops. Two experiments involved red clover as a cover crop, while two experiments involved both a grass and leguminous cover crop (fall rye and red clover respectively). Cover crops were underseeded into winter wheat and achieved up to 4 t ha^{-1} of biomass production by the late fall of the seeding year. Soil nitrate levels in the first month after planting corn were much lower following no tillage than with moldboard plowing. Later plowing dates and chemical kill dates (in no-till plots) were associated with a delay in nitrate N release. The soil nitrate N test did not provide accurate estimates of N fertilizer requirements of no-till corn after cover crops, even when nitrate sampling was delayed until 5 weeks after planting.

INTRODUCTION

A soil nitrogen (N) test has been used by commercial corn farmers in Ontario since the spring of 1991. Current recommendations include sampling to a depth of either 30 or 60 cm within 5 days of planting corn (1). Most of the Ontario recommendations have been based on sampling at planting, rather than side-dress sampling (i.e. when corn plants are 15-30 cm tall) as is recommended in U.S. Corn Belt States, since over 70% of our farmers apply all of the nitrogen fertilizer before corn emerges. Nitrogen fertilizer is often incorporated before planting corn, or broadcast together with herbicides between planting and emergence.

One of the difficulties in the interpretation of the soil N test is whether the nitrate N levels reported accurately reflect the nitrate N actually available to the corn crop from grass or leguminous cover crops which commonly precede corn. A second concern is whether the release of nitrate N from cover crops to corn are influenced by tillage systems, or by the timing of kill in a no-till system. Providing accurate credit to the nitrogen released from cover crops may be almost impossible when leguminous cover crops such as red clover are chemically killed or incorporated in the spring. Furthermore, if less nitrate N is available after cover crops to no-till corn, savings in fuel, labour and capital costs with no-till may be partially offset by higher nitrogen fertilizer costs.

The primary purpose of this research was to evaluate the timing of nitrate N release in soil with various tillage systems after cover crops. Corn response (whether fertilized with additional N or not) to tillage after cover crops was also of interest.

MATERIALS AND METHODS

Experiment I

Field experiments involving red clover as the sole cover crop were established on silt loam soil near Elora, Ontario. Red clover (cv. Walter) was underseeded into winter wheat the previous year and the treatments included two dates of chemical kill in spring (April 25 and May 10) plus three dates of moldboard plowing (Nov. 25, April 25 and May 10) for corn that was planted by May 15. First-year corn response following the wheat plus clover treatments was measured in both 1992 and 1993 on adjacent sites. The experimental design was a split-plot design with four replications; cover crop/tillage were the main treatments and two rates of N (0 and 150 kg ha^{-1}) were the sub-plots.

Cover crop biomass and N concentrations were determined in late October or early November of the establishment year. Soil samples for nitrate N determination were taken from 0-30 and 30-60 cm depth intervals in May, June and July after planting corn. Corn biomass yields and N concentrations were determined in early July and at final harvest in October. Only grain yields are reported here.

Experiment 2

Cover crop treatments were established following winter wheat on a Fox sandy loam and a Perth clay loam soil in 1992. The three cover crop treatments included red clover (underseeded in March), fall rye (cv. Danko) (seeded after wheat grain harvest) and no cover crop. The tillage systems compared were fall plowing (i.e. chisel plowing in sandy loam and moldboard plowing in the clay loam) followed by spring cultivation, and no-till following chemical kill of the cover crops (in either late October of 1992 or early May of 1993). Corn was planted on May 8 and 11, respectively for the two soil types. One-half of each plot received no nitrogen fertilizer while the other half received 150 kg N ha^{-1} applied as liquid urea ammonium nitrate between corn rows in mid June. The experiment was, therefore, arranged in a split-plot design with cover crop/tillage treatments as main plots and nitrogen rate as sub-plots. There were 4 replications. Soil and crop measurements were similar to those in Experiment I above.

RESULTS AND DISCUSSION

Experiment I

An average of 2.7 t ha^{-1} of red clover shoot growth had accumulated by late November of 1992 and 1993 at the respective sites (data not shown). Since the shoot biomass alone averaged 2.6% N, approximately 70 kg ha^{-1} of N was accumulated in that fraction. Root accumulation of N by red clover underseeded into cereal crops averages about 80% of total N in shoots in late fall at this location (2); thus estimated total N uptake averaged 130 kg ha^{-1}.

Soil nitrate N concentrations were higher after moldboard plowing compared to no-till on most sampling dates in 1992 and 1993 (Figures 1 and 2). Fall plowing generally resulted in higher nitrate levels than moldboard plowing in spring just before planting. With the no-till system, earlier chemical kill (i.e. late April) resulted in a faster buildup in soil nitrate levels than chemical kill just before planting. Similarly, moldboard plowing two weeks earlier in spring also resulted in higher soil nitrate levels in May and early June. The results in Figures 1 and 2 suggest that it is impossible to accurately predict nitrogen fertilizer requirements following red clover if soil sampling is done in May. When red clover was moldboard plowed, nitrate levels were high enough (i.e. soil above 20 mg/kg) by mid-June of 1992 to suggest that

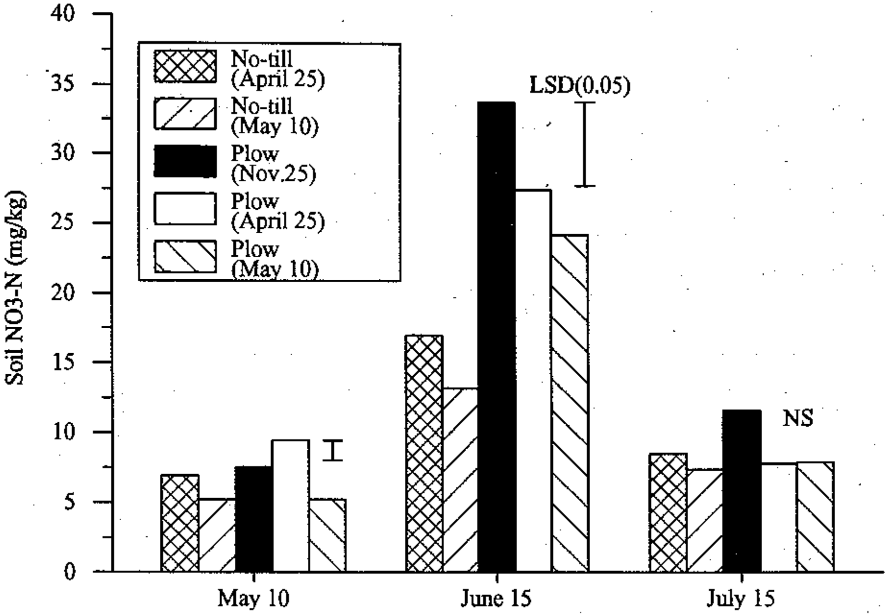

Fig. 1 Soil Nitrate-N Concentration for various tillage systems after Red Clover (Elora 1992).

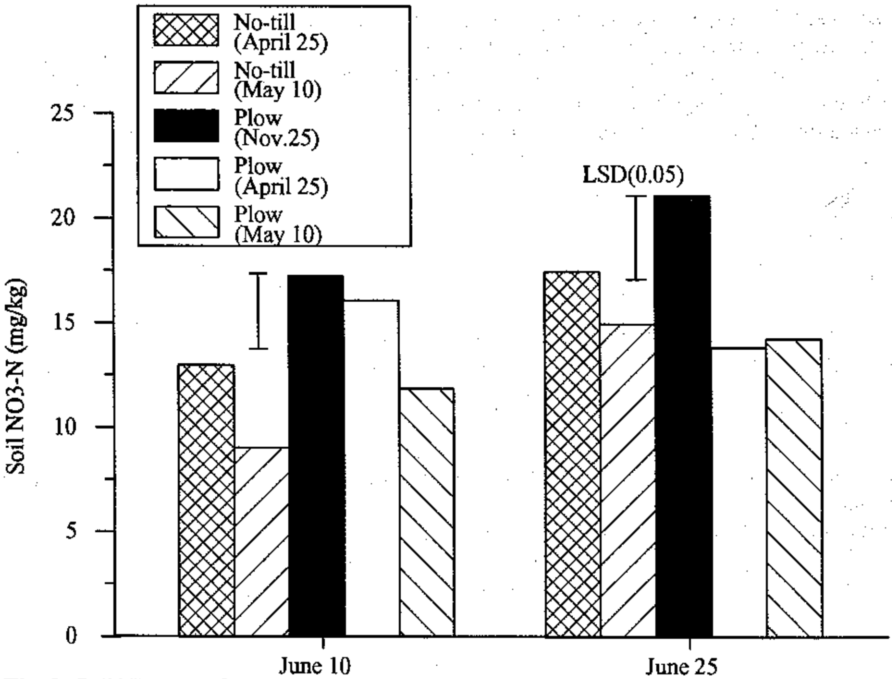

Fig. 2 Soil Nitrate-N Concentration for various tillage systems afer Red Clover (Elora 1993).

additional N fertilizer was not necessary to maximize corn yields. In the no-till treatments, soil nitrate levels were low enough in mid-June of 1992 and 1993 to warrant N fertilizer applications ranging from 10 to 110 kg N ha^{-1}.

Corn yields were not increased by N fertilizer application in any of the tillage systems (Figure 3). Hesterman *et al.* (3) also observed that no-till corn yields did not respond to fertilizer N application after red clover underseeded into winter wheat. Although no-till systems resulted in corn yield reductions of 17% relative to the moldboard plowing treatments (Figure 3), neither the timing of moldboard plowing nor the timing of chemical kill had any significant impact on the relative corn yields with the two systems. Corn yield response differences were due to factors other than nitrogen availability or soil moisture depletion.

Experiment 2

By November of 1992, approximately 2.4 t ha^{-1} of red clover shoot growth had accumulated, while only 0.9 t ha^{-1} of fall rye had accumulated. After red clover, soil nitrate N concentrations were highest with fall plowing at both the sandy loam and silt loam locations in May of 1993 (Figures 4 and 5). On June 10, tillage system had no influence on soil nitrate levels on the sandy loam site, while on the clay loam site moldboard plowing after red clover resulted in approximately double the nitrate levels than occurred with the no-till treatments. However, fall kill of red clover (clay loam site only) resulted in higher soil nitrate levels than after chemical kill of no-till in May for the June 10 sampling date.

Following fall rye and no cover crop, soil nitrate levels were similar for no-till and plowing treatments at both locations in early May (Figures 4 and 5). On June 10 after fall rye, however, October killed plots had significantly higher nitrate levels than other tillage treatments on the sandy loam site, while plowed plots had significantly higher levels than the two no-till treatments on the clay loam site. The relatively low soil nitrate levels on June 10 following fall chisel plowing of fall rye (Figure 4) may have been due to the rye regrowth in the spring until secondary tillage operations on May 10. Overall, nitrate levels after no cover were significantly below those following red clover - but somewhat higher (on average) than nitrate levels following fall rye.

Corn yields with no nitrogen fertilizer application were significantly higher following red clover, than the other cover crop treatments at both sandy loam and clay loam sites (Table 1). Unfertilized corn yield increases due to the red clover treatment ranged from 1.2 to 1.8 t ha^{-1} with the no-till system and from 2.4 to 4.1 t ha^{-1} with the plowed system. Kill date had no significant effect on corn yields in the no-till system following either red clover or fall rye. Unfertilized no-till corn yields were even lower after rye than they were after no cover plots. Our results suggest that cereal rye cover crops may not be desirable prior to corn in Ontario, despite the evidence that cereal rye can recover more residual fertilizer N than leguminous cover crops in humid climates (4).

When 150 kg/ha of nitrogen fertilizer was applied, yield differences among cover crop/tillage combinations were generally nonsignificant. Corn yields did not increase significantly with the nitrogen fertilizer application for any of the tillage systems following red clover on the sandy loam site. Corn yields also failed to increase significantly after red clover on the clay loam site when moldboard plowing was used. Corn yields increased significantly with nitrogen fertilizer in all other cover crop and tillage systems.

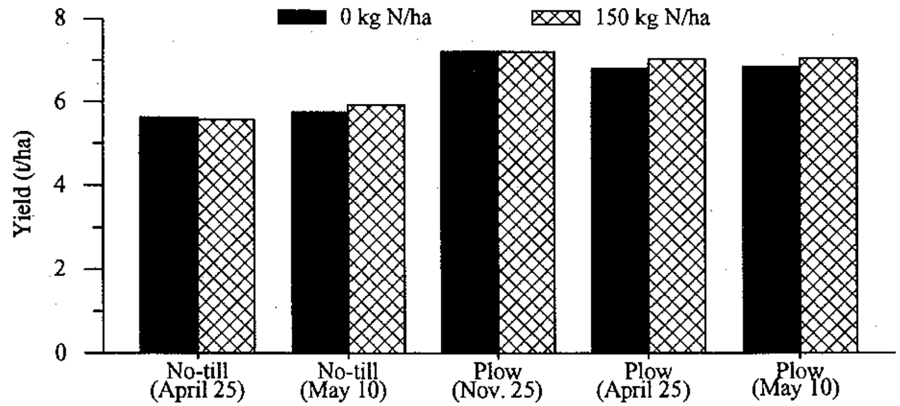

Fig. 3 Corn yields for various tillage systems and two nitrogen fertilizer levels after red clover (Elora 1992-93)

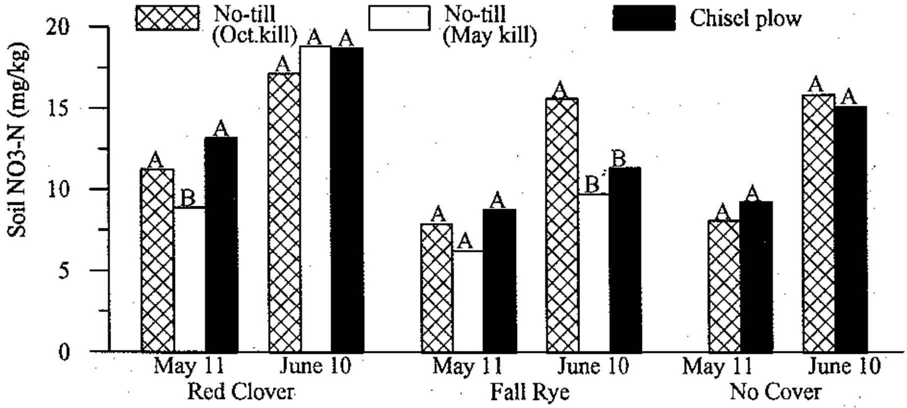

Fig. 4 Cover crop and tillage system effects on soil nitrate levels in May and June on sandy loam soil (1993).

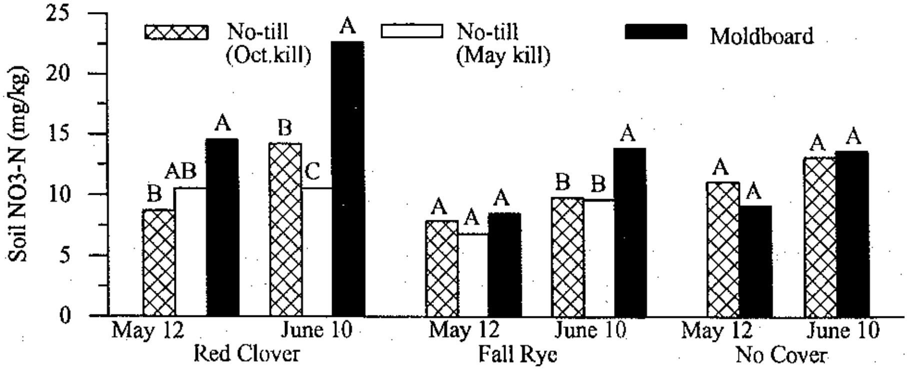

Fig. 5 Cover crop and tillage system effects on soil nitrate levels in May and June on clay loam soil (1993)

Table 1 Cover crop, tillage system and nitrogen fertilizer effects on grain corn yields at two sites in 1993.

Cover crop	Tillage	Sandy loam 0 N		Sandy loam 150 kg N	Clay loam 0 N		Clay loam 150 kg N
		Yield (t ha^{-1})					
Red clover	No-till (Oct. kill)	8.37		9.30	7.71	*	9.66
	No-till (May kill)	8.42		9.35	7.39	*	8.66
	Plow (Nov.)	8.66		9.29	9.18		9.82
Fall rye	No-till (Oct. kill)	6.03	*	8.81	4.91	*	9.86
	No-till (May kill)	6.26	*	9.51	4.05	*	9.72
	Plow (Nov.)	6.50	*	8.83	5.47	*	9.63
No cover	No-till	7.24	*	9.55	5.57	*	9.92
	Plow (Nov.)	6.30	*	8.62	5.02	*	9.33
Tillage LSD (0.05) within cover		1.11		1.02	0.88		0.69
CV (%)			7.88			7.2	

* Differences between nitrogen rates are significant at P=0.05.

Recommended nitrogen rates following red clover (based on soil nitrate-N concentrations in June) averaged 76 and 117 kg ha^{-1} for the no-till system and 67 and 27 kg ha^{-1} for the plow system on the sandy loam and clay loam sites, respectively. The small corn yield increases with the 150 kg N rate suggests that the soil nitrate test overestimated the nitrogen requirements following red clover, especially with no-till.

CONCLUSIONS

1. Soil nitrate N levels in spring are much lower with no-till than with plowed systems after a red clover cover crop. 2. Soil sampling for nitrate N determination could not provide accurate recommendations on fertilizer N requirements for corn production following red clover. 3. Later plowing dates and chemical kill dates (with no-till) delayed soil nitrate N release.

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N-FERTILIZATION OF CEREALS UNDER REDUCED TILLAGE

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ABSTRACT

Growth and nitrogen uptake patterns of spring cereals were studied over two seasons in two long-term tillage trials on loam soil, on which tillage treatments comparing reduced tillage with a conventional system had been established more than 10 years previously. Levels of mineral nitrogen in the soil were monitored, and net mineralisation rates were assessed using "field incubation". Overall growth, yield levels and responses to nitrogen fertilizer were very similar with both tillage systems. There were significantly higher plant-N concentrations with reduced tillage in one of the trials. Soil mineral nitrogen levels were also often higher with reduced tillage in that trial. This may account for the higher lodging which is sometimes found with reduced tillage. No difference was found in the nitrogen mineralisation rate, and no evidence was obtained which suggests that nitrogen fertilization of cereals should be modified on the basis of tillage system.

INTRODUCTION

Reduced tillage leads to changes in many of the soil's physical properties, several of which may be expected to be of importance for the turnover of nitrogen. Soil bulk density often increases in the middle topsoil horizon in the absence of ploughing. This leads to reduced air-filled pore space and higher water contents and may alter the soil's thermal properties. Increased volumetric beat capacity may result in lower diurnal temperature amplitude and the presence of crop residues on the surface reduces soil temperatures markedly in the early part of the growing season due to greater reflectivity and insulation (1). It is reasonable to assume that lower nitrogen mineralisation may result from such cbanges.

Under conditions in Germany, it has been suggested that nitrogen availability in the soil increases with increasing tillage depth (2), and that immobilisation increases under conservation tillage, resulting in lower nitrate concentrations in the soil solution (3). This suggests that N-fertilizer requirements may actually increase with reduced tillage. However, the question is complicated by the fact that growth retardation, caused for example by unfavourable seedbed conditions or increased weed competition, may be partly offset by higher fertilization, even though such factors have little to do with nitrogen availability.

Other factors, on the other hand, may lead to increased nitrogen availability. The accumulation of organic matter which normally occurs in the upper soil layers represents an increase in nitrogen reserves, which in the long term may become availahle to plants. Furthermore, the omission of autumn ploughing prevents the stimulation of mineralisation at a time when there is a high risk of nutrient leaching. English and Danish investigations have demonstrated reduced nitrogen leaching in winter in the absence of autumn ploughing (4,5,6,7). Reduced leaching in spring has been demonstrated in Norway as a result of greater surface runoff from unploughed land during the snow-melt period (8).

Norwegian tillage trials have in several cases given results which indicate that reduced tillage affects the crop's nitrogen supply, but we know little about the mechanisms involved. Significant increases in cereal lodging have been found after only a few years with reduced tillage (9,10). Pronounced changes related to tillage have also been found in the development pattern and nitrogen concentrations of potatoes (11). An explanation for both these findings may be an increase in the release and uptake of nitrogen during the latter part of the growing season.

Studies of nitrogen levels in soil and plants were performed in 1991 and 1992 on two long-term tillage trials started in 1980, in which yields have for many years been maintained at a level similar to that obtained with conventional tillage.

MATERIAL AND METHODS

Field trials

Both trials are on moderately well-drained morainic loam soil with high organic matter content (approx. 6-8% humus). Both include two tillage treatments (reduced versus conventional tillage), with four replicates in each. Reduced tillage comprised in this case the use of a machine (TUME fertilizer harrow) with spring tine coulters for fertilizer and seed placement, in two separate passes, followed by rolling. Straw was removed and the stubble burnt on these plots. Conventional tillage comprised autumn ploughing followed in spring by levelling, harrowing, fertilizing and sowing as above.

Four levels of nitrogen fertilizer were employed in 1991-1992, given as calcium nitrate in a single dressing within the seedbed (0, 60, 90 and 120 kg N/ha). One of the trials was irrigated (twice in 1991 and four times in the very dry year of 1992), whilst the other trial was rainfed only. The latter site was where the previously mentioned observations of increased cereal lodging and altered potato development were made. Spring barley was grown in both trials, with spring wheat in addition in the irrigated trial.

Plant sampling

All above-ground plant material was removed on five occasions during the growing season from 1 m² sub-plots of the spring barley treatments with 0 and 90 kg N/ha. Sampling began in early June and was repeated at fortnightly intervals. Straw and grain was weighed at final harvest from 15 m² of all treatment plots. The total nitrogen concentration of all samples was analysed.

Soil sampling

Topsoil (0-20 cm) contents of nitrate and ammonium (N-MIN) were measured on all plots included in the above-mentioned plant sampling. In each case the sampled area was thereafter covered with transparent polythene, held in place by a steel frame, in order to prevent leaching and/or evaporation. The same area was resampled after 14 days, and the observed differences in N-MIN content were designated "net mineralisation". Regrowth of plants on harvested sub-plots was prevented by pulling up the stubble remains.

RESULTS AND DISCUSSION

Dry matter development and N concentrations

The main effects of tillage treatment and nitrogen fertilization on these parameters are shown in table 1, averaged over both trials and years.

Table 1. Main effects of tillage and fertilization on dry matter development (tonnes/ha) and N concentration (%) at different stages in the growing season.

	Sampling no. (approx. date)				
	1 (14/6)	2 (28/6)	3 (12/7)	4 (26/7)	5 (9/8)
DRY MATTER					
Reduced tillage	0.73	2.48	4.50	5.94	6.43
Conv. tillage	0.95	2.60	4.66	5.78	6.16
		Tillage treatment n.s.			
N-CONCENTRATION					
Reduced tillage	3.77	2.01	1.37	1.06	1.13
Conv. tillage	3.38	1.79	1.32	1.02	1.14
		Tillage x sampling no. p<0.01			
DRY MATTER					
Unfertilized	0.56	1.57	3.05	3.96	4.15
90 kg/ha N-fertilizer	1.12	3.51	6.11	7.76	8.45
		N-fert. x sampling no. p<0.001			
N-CONCENTRATION					
Unfertilized	3.26	1.68	1.17	0.95	1.08
90 kg/ha N-fertilizer	3.89	2.12	1.52	1.14	1.19
		N-fert. x sampling no. p<0.001			

There was slightly poorer initial growth on the unploughed plots, but this was compensated for later. There were significantly higher N concentrations on these plots during the early part of the season, but later on there was no difference. The difference in N concentration during the early part of the season was of the same magnitude (by interpolation) as that caused by fertilization with 50-60 kg N/ha. Part, but probably not all, of this difference may be attributed to the difference in dry matter development.

Dry matter development was similar in both trials in 1991, when rainfall was adequate from early June onwards, but much lower in the non-irrigated trial in 1992, when dry conditions lasted until July. There were lower initial N concentrations in both trials in the latter year, presumably due to poor uptake under the dry conditions.

Final yields of grain and straw

Overall grain yields of spring barley were 5% higher ($p<0.06$) with conventional than with reduced tillage, whilst the difference in straw yield was not significant (table 2). There was no significant interaction with N-fertilizer level in either case. The dry conditions in 1992 restricted the N-response in the non-irrigated trial. Highest yields were obtained in all other cases at the highest level of N-fertilizer (120 kg/ha).

The N-response curves for grain yield under good growth conditions appear to be very similar for both tillage systems. Fig. 1 is derived from the above data, excluding data from the non-irrigated trial in 1992, but including data for spring wheat from the irrigated trial in both years and for spring barley in 1990 from the non-irrigated trial. There was little overall difference in lodging in these trials, and weed incidence was fairly low.

Table 2. Final yields of spring barley grain and straw (tonnes/ha) in relation to fertilizer level, tillage system and means for individual trials and years.

	GRAIN YIELD					STRAW YIELD				
kg/ha N fert.:	0	60	90	120	Mean	0	60	90	120	Mean
Red. tillage	2.1	4.2	4.5	4.8	3.9	1.9	3.6	4.0	4.3	3.5
Conv. tillage	2.3	4.6	4.5	5.1	4.1	1.9	4.0	4.0	4.5	3.6
	N-fert. p<0.001 Till. p<0.06					N-fert. p<0.001 Till. n.s.				
IRRIGATED TRIAL										
1991	2.1	4.5	4.7	4.8	4.0	2.0	5.0	5.4	5.3	4.4
1992	2.6	4.4	5.2	6.0	4.6	2.4	3.2	3.2	3.6	3.1
NON-IRRIGATED TRIAL										
1991	2.2	5.3	5.1	5.7	4.5	2.1	5.0	5.2	5.7	4.5
1992	2.0	3.4	3.1	3.4	3.0	1.0	2.0	2.1	2.9	2.0
	Year x Trial x N-fert. p<0.001					Year x Trial p<0.001				

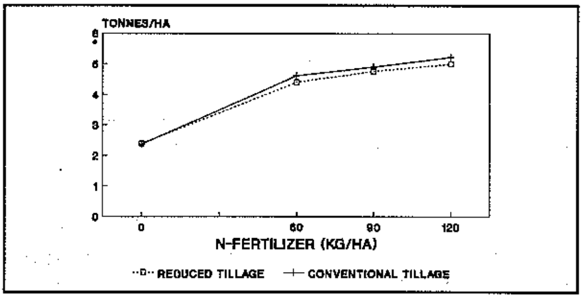

Fig. 1. Grain yield N-response curves for spring barley and spring wheat grown with reduced or conventional tillage systems. Mean of 6 harvests.

Nitrogen in grain and straw

The N concentrations in grain and straw were in both years higher after reduced tillage than after conservation tillage in the non-irrigated trial (table 3). This is, as mentioned above, the trial site at which higher lodging has frequently been observed with reduced tillage. On the other trial, however, the effect of tillage was less marked, and sometimes showed an opposite trend. In this trial there was more lodging after conventional tillage in 1991.

There was no interaction between tillage and fertilizer level. Concentrations increased, as expected, with level of N-fertilizer, especially at the highest rate. Apparent N recoveries in grain plus straw declined from around 75% with the use of 60 kg/ha N-fertilizer to 60% at both higher application levels, with little difference between tillage systems.

Table 3. Mean N concentrations (%) in grain and straw following different tillage treatments.

	GRAIN		STRAW	
	1991	1992	1991	1992
NON-IRRIGATED TRIAL				
Reduced tillage	1.76	2.31	0.64	1.04
Conventional tillage	1.70	2.24	0.54	0.88
	p<0.001	n.s.	p<0.05	p<0.05
IRRIGATED TRIAL (barley)				
Reduced tillage	1.51	1.50	0.47	0.58
Conventional tillage	1.52	1.40	0.46	0.65
	n.s.	n.s.	n.s.	p<0.05
IRRIGATED TRIAL (wheat)				
Reduced tillage	1.86	1.87	no	0.56
Conventional tillage	1.86	2.13	data	0.61
	n.s.	p<0.05		n.s.

Mineral nitrogen (N-MIN) in soil

Average values for N-MIN at different times during the growing season were similar on both sites i 1991, but higher in the non-irrigated trial in 1992, due to lower plant uptake of nitrogen. There was a positive net mineralisation in all cases except early in 1992, when the dry conditions led to a net immobilisation on both sites. An extra sampling was therefore made in 1992, and data from the first sampling was ommitted in later calculations.

Table 4 shows average N-MIN concentrations, with and without fertilizer, in relation to tillage. There was generally little difference between tillage treatments in the irrigated trial, but tillage had a marked effect in the non-irrigated trial, particularly on fertilized plots, where there were higher levels following reduced tillage, both before and after field incubation. The 3-way interaction (tillage x trial x fert.) was significant in most cases.

Table 4. N-MIN concentrations in topsoil (mg/100g dry soil) before and after field incubation period of 14 days. Means of four sampling periods in each case.

	1991				1992			
N-fert. (kg(ha):	N0	N90	N0	N90	N0	N90	N0	N90
	BEFORE		AFTER		BEFORE		AFTER	
IRRIGATED TRIAL								
Reduced tillage	0.52	1.00	0.97	1.45	0.54	0.51	0.72	0.77
Conv. tillage	0.48	0.92	0.97	1.42	0.55	0.58	0.72	0.72
NON-IRRIG. TRIAL								
Reduced tillage	0.51	1.22	1.12	2.08	0.62	2.24	0.98	2.60
Conv. tillage	0.42	0.85	1.06	1.15	0.51	0.82	0.71	1.07
Significance:								
Trial	n.s.		n.s.		p<0.01		p<0.01	
Tillage	n.s.		p<0.05		p<0.05		p<0.01	
N-fert.	p<0.001		p<0.001		p<0.001		p<0.001	
3-way interaction	n.s.		p<0.05		p<0.01		p<0.05	

There was high variability in the amount of nitrogen released during the incubation period, and no significant effects were detected between tillage treatments or fertilizer levels in either trial (table 5).

Table 5. Mean net mineralisation rates found during periods of field incubation (kg N/ha/day).

	TILLAGE TREATMENT			FERTILIZER TREATMENT		
	Reduced	Conventional	s.e.	N0	N90	s.e.
1991	1.06	0.87	0.18 n.s.	0.98	0.95	0.12 n.s.
1992	0.52	0.34	0.18 n.s.	0.41	0.45	0.21 n.s.

CONCLUSION

The growth and nitrogen uptake patterns of spring barley appeared to be little affected by tillage in either trial. Grain and straw yield rsponses to nitrogen fertilizer were similar with both tillage treatments, and increased up to 120 kg N/ha except under drougbt conditions. The yields obtained with reduced tillage were only slightly lower than those following conventional tillage. Plant N concentrations were in some cases higher with reduced tillage than after ploughing, particularly in the non-irrigated trial. This result is in agreement with previous findings of more frequent lodging in cereals and prolonged growth of potatoes with reduced tillage which have been made at the same trial site. Soil N-MIN levels in the growing season were often higher with reduced tillage than with conventional tillage in the latter trial, but little difference was found in the irrigated trial. There was no demonstrable difference in mineralisation rate between tillage treatments at either site.

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TROPICAL CORN RESPONSE TO NITROGEN AND STARTER FERTILIZER UNDER STRIP AND CONVENTIONAL TILLAGE SYSTEMS

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ABSTRACT

Tropical maize (*Zea mays* L.) is a promising new crop for the southeastern U.S., but optimum management practices have not been established for the crop. Field studies were initiated in 1990 to evaluate tropical maize response to N and starter fertilizer under conventional and conservation tillage. The experiment was conducted on a Dothan fine sandy loam (Plinthic Paleudults). Treatments included conventional (chisel plowing, disking, and in-row subsoiling) and strip tillage (in-row subsoiling only into cover crop (*Triticum aestivum* L.) residue) tillage systems; four N rates (0, 56, 112, and 168 kg ha^{-1}); and five starter fertilizer combinations: 1) no starter, 2) 22.4 kg N ha^{-1}, 3) 22.4 kg P ha^{-1}, 4) 22.4 kg N + 22.4 kg P ha^{-1}, and 5) 22.4 kg N, + 22.4 kg P, + 11.2 kg S ha^{-1}. Silage yields (averaged over 1990 and 1991) under conventional tillage were 14% lower than with strip tillage. Grain yields in 1991 were 30% lower with conventional tillage than with strip tillage. Differences among tillage systems were not significant in 1992. Silage and grain yields increased with N rate with the largest response to N occurring in 1991 under strip tillage. The best starter fertilizer for silage was the N + P (NP) treatment. For grain, N alone gave the same yield as the NP starter in 1991, with the greatest response occurring under conventional tillage. In 1992 the NP treatment was the best starter for grain.

INTRODUCTION

Tropical maize has become an important alternative crop in the southeastern United States during the past few years. It has been estimated that over 20,000 ha were grown in 1991, primarily for silage (1). Due to its late planting date, tropical maize serves as an alternative crop in double-cropping systems using soybean (*Glycine max* (L.) Merr.), grain sorghum (*Sorghum bicolor* (L.) Moench) and temperate maize (*Zea mays* L.) (2,3,4,). Obtaining a late season grain or silage crop, in addition to high silage yields, makes tropical maize an attractive alternative crop for the South.

Double-cropping tropical maize with wheat (*Triticum aestivum* L.) using conservation tillage would be a desirable system. The system would be environmentally sound and potentially increase the sustainability of an existing farm by providing an extra source of silage/grain as well providing more ground cover throughout the year. However, little data has been reported regarding the N requirements of tropical maize when grown as a double-crop, under no-till or conventional tillage systems (5). There is also a need to assess starter fertilizer needs for tropical maize when grown as a double-crop, under conservation and conventional tillage systems.

The objective of this study was to evaluate the response of tropical maize to N and starter fertilizer when grown under conventional and conservation tillage systems.

MATERIALS AND METHODS

To determine optimum management practices for tropical maize in south Alabama (southeastern USA), a three-year field study was initiated in 1990 on a Dothan sandy loam soil (fine-loamy siliceous thermic Plinthic Paleudult). Tropical maize hybrid Pioneer 304C was planted on 1 June in 1990 and tropical maize hybrid Pioneer 3072 was planted on 4 June 1991 and 13 June 1992. The experiment was a split-split plot design with the two tillage systems as whole plots, starter fertilizer treatments as split plots and N rates as split-split plots. Tillage treatments consisted of strip and conventional tillage. The five starter fertilizer treatments were: 1) no starter, 2) 22.4 kg N ba^{-1}, 3) 22.4 kg P ha^{-1}, 4) 22.4 kg N + 22.4 kg P ha^{-1}, and 5) 22.4 kg N, + 22.4 kg P , + 11.2 kg S ha^{-1}.

Wheat was planted each fall. After the wheat matured in late spring, the test area was prepared according to tillage system. Conventional tillage consisted of chisel plowing and disking followed by in-row subsoiling at planting. Strip tillage consisted of in-row subsoiling and planting into wheat stubble. This resulted in a 20- to 30- cm wide tilled zone. Depth of subsoiling for both tillage systems was approximately 40 cm. Subsoiling was necessary since the Dothan soil develops a hard pan at the bottom of the plow layer. The starter treatments were applied at planting as a solution in an approximate 5 x 5 cm placement. Nitrogen as ammonium nitrate was applied as a sidedress approximately 4 weeks after planting. Each plot was 9.12 m in length and consisted of 8 rows with a 91.4 cm spacing. Plant population for all three years of the study was approximately 49,400 plants ha^{-1}.

Grain was harvested from the two middle rows of all plots on 10 October 1991 and 14 October 1992. Grain yields were not determined in 1990 due to severe insect pressure. Grain moisture was corrected to 155 g kg^{-1}.

Silage yields were determined by cutting a total of 3.04 m of row per plot. Silage was harvested on 28 August, 5 September, and 9 September in 1990, 1991 and 1992, respectively. The whole plants were weighed and subsamples collected to determine dry matter content. Subsamples were dried at 60°C and weighed. Silage yields were corrected to a moisture content of 650 g kg^{-1}.

In 1991 and 1992, subsamples of silage were analyzed for forage quality. The silage was analyzed for crude protein, acid detergent fiber (ADF) and neutral detergent fiber (NDF).

Using SAS procedures (6), yield and forage quality were statistically analyzed. Means were separated with Fisher's protected LSD.

RESULTS AND DISCUSSION

In 1990, there were no interactions between tillage, starter fertilizer, or nitrogen. Excellent silage yields were obtained with the conventional and strip tillage systems averaging 38.3 and 45.5 Mg ha^{-1}, respectively. The addition of N increased yields, but a significant response was only obtained up to the 56 kg ha^{-1} rate . This response, was most likely due to the variety grown in 1990 (Pioneer 304C) as well as drought conditions and severe infestation of fall armyworm (*Spodoptera frugiperda* J.E. Smith). Starter fertilizer also increased yields (Table 1), with the NP starter increasing silage yields by 6.9 Mg ha^{-1}.

Table 1. Tropical maize silage yields in 1990 and 1991 averaged over N rates as affected by starter fertilizer treatments.

		1991	
Starter Fertilizer[1]	1990[2]	Conventional	Strip
	--------Mg ha-1	--------	--------
None	37.9	21.3	21.7
N	41.9	19.9	24.6
P	38.8	22.0	22.4
NP	44.8	23.7	25.3
NPS	46.1	20.6	24.0
$LSD_{0.10}$	4.7	2.24[3]	

[1] 22.4 kg N ha^{-1}, 22.4 kg P ha^{-1}, 11.2 kg S ha^{-1}.
[2] Averaged over tillage treatments.
[3] Interaction LSD.

In 1991, silage and grain yields increased with N rate (Table 2) with consistently higher yields occurring under strip tillage. The best starter treatment for silage was the NP treatment under the strip tillage system (Table 1). For grain, N alone as a starter was adequate, averaging 3951 kg ha^{-1} over tillage systems (data not shown).

In 1992, grain (Table 2) and silage yields were much lower and the two tillage systems produced similar yields. Grain yields for all treatment combinations in 1992 ranged from 690 to 3261 kg ha^{-1} and increased with increasing rates of N (Table 2). The best starter for grain was the NP treatment (data not shown). Low grain yields were the result of low rainfall distribution. This was in contrast to results obtained at two other locations in Alabama in 1992. Grain yields at these locations averaged above 6270 kg ha^{-1} when using the same variety and similar planting dates.

Forage quality of the harvested silage was affected primarily by the rate of N (Table 3). As expected, crude protein increased with increasing N rate. Both ADF and NDF decreased with increasing N rate.

Table 2. Tropical maize silage yields in 1990, silage and grain yields in 1991 and grain yields in 1992 (averaged over starter treatments) as affected by the rate of N fertilizer.

		1991				1992	
	1990	Silage		Grain		Grain	
N Rate	Silage	Conv.[1]	Strip[1]	Conv.	Strip	Conv.	Strip
- kg ha^{-1} -	---------- Mg ha^{-1} ----------			---------- kg ha^{-1} ----------			
0	36.5	15.5	14.1	1630	1819	1819	1442
56	39.9	20.2	24.0	2885	3888	2258	2132
112	41.0	24.4	26.9	3512	4641	2634	2822
168	40.1	26.0	29.8	3763	5080	2822	2446
$LSD_{0.05}$	4.48	ns[2]		11.2		10.6	
$LSD_{0.10}$	---	2.69		---		---	

[1] Conv. = conventional tillage; strip = strip tillage.
[2] Interaction LSD. ns = nonsignificant.

Table 3. Tropical maize forage quality in 1991 and 1992 as affected by the rate of N fertilizer.

	Crude Protein		NDF[1]		ADF[2]	
N Rate	1991	1992	1991	1992	1991	1992
- kg ha-1 -	---------- % ----------					
0	4.6	4.8	59	62	33	36
56	4.9	5.3	56	59	30	33
112	5.7	6.0	54	57	28	32
168	6.3	6.5	53	57	27	31
$LSD_{0.05}$	0.8	1.0	1.2	1.0	0.97	1.4

[1] NDF = neutral detergent fiber.
[2] ADF = acid detergent fiber.

CONCLUSIONS

The conservation tillage practice of strip tillage gave higher silage yields in 2 of 3 years and higher grain yields in one of two years measured when compared to conventional tillage. Higher silage yields were obtained with the NP starter when averaged over both tillage systems in two of three years. For grain, N alone as a starter fertilizer gave the best results under strip tillage, whereas NP was the best starter under conventional tillage. In 1990, due to variety (Pioneer 304C), and drought and insect pressures, silage yields did not increase above a rate of 56 kg N ha^{-1}. Previous work in the southeastern U.S. has shown that Pioneer 304C has a low optimum N rate. In 1991 and 1992, Pioneer 3072 was grown and rainfall was adequate. An increase in silage yields was obtained up to the 168 kg ha^{-1} N rate. Results of this test demonstrate that tropical maize will perform well in conservation tillage systems. Inclusion of tropical corn in rotations involving conservation tillage could help increase the profitability and sustainability of farming systems in the southeastern U.S.

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INFLUENCE OF LONG-TERM TILLAGE, STRAW AND N FERTILIZER ON BARLEY YIELD AND ON N UPTAKE

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ABSTRACT

Long-term influence of N fertilizer, tillage and straw on crop production and soil properties are not well known in central Alberta. Field experiments were established in fall, 1979, on a Black Chernozemic soil and on a Gray Luvisolic soil in north-central Alberta to determine the long-term effect of tillage, straw and N fertilizer on yield and N uptake of barley. Fertilizer N was applied annually at 56 kg ha^{-1}. On the average of 11 years, barley yield and N uptake were lower under zero tillage than conventional tillage. Retention rather than removal of straw tended to reduce barley yield for 6 and 2 years at Site 1 and 2, respectively. A simple mathematical model of average annual plant N uptake and grain yield accounted for most of the variation in the data observed at both sites ($R^2 \geq 0.907$). Final values of soil N, calculated using a mass balance approach, agreed closely with values measured at the end of the 11th year. Conventional tillage and zero tillage, with addition of fertilizer N and retention of straw, were the only treatments with apparent net addition of N to soil at Site 1. At Site 2, the same was true only for the zero tillage treatment.

INTRODUCTION

Cultivated soils of north-central Alberta, Canada, are productive but subject to water erosion and soil organic matter loss. Zero tillage, or direct seeding, is a conservation farming system that is increasingly appealing to producers in the area. Benefits of this farming approach in terms of long-term sustainability of soil and water resources and profitability have been indicated worldwide (Carter 1993). There are constraints, however, that appear to prevent its quick adoption by local producers (Larney et al., 1993). One such constraint is the handling of heavy amounts of straw under continuous, or semi-continuous, cereal grain production. This is true especially with barley (*Hordeum vulgare* L.), a major crop in the area. Two concerns arise regarding straw handling under reduced tillage systems. One is increased N immobilization caused by continuous straw addition (Malhi et al. 1989) with the question of whether immobilization decreases with years. The other is a possible negative effect of straw baling on soil quality (Campbell et al., 1991).

Regardless, changes in soil quality caused by either retaining or removing straw would likely be measurable under medium to long-term conditions. Two long-term field experiments were initiated at two sites in north-central Alberta in the fall of 1979. In a previous paper, Nyborg et al. (1994) reported the influence of fertilizer N application, straw handling, and tillage methods on the soil organic C and N contents after 11 years of conducting these experiments. In this paper, we report on the long-term influence of these tillage methods, straw handling techniques, and N application on barley yield and N uptake.

MATERIALS AND METHODS

Two experimental sites were chosen, with Site 1 at Breton, Alberta (53° 07'N, 114° 28'W), on a Gray Luvisolic soil of the Breton loam series and with Site 2 at Ellerslie, Alberta (53° 25'N, 113° 33'W), on a Black Chernozemic soil of the Malmo silty clay loam series. Slope gradients at Sites 1 and 2 were 3 and 1 %, respectively. Normal annual precipitation at Sites 1 and 2 is 546 and 412 mm, respectively. The experimental area at both sites was square with sides of 28 m. The experimental design was randomized complete block with four replicates. Experimental unit was 6.9 m long by 2.8 m wide.

Soil organic carbon at the 0 to 15 cm depth at the beginning of the experiment was 12 and 49 g kg^{-1} for Sites 1 and 2, respectively. Previous cropping had been to cereal grains and both sites had shown symptoms of N deficiency, especially Site 1. The experiment was initiated in the fall of 1979 to investigate the effect of tillage (zero and conventional), straw handling (removed and retained), and N fertilization (0 and 56 kg ha^{-1} $year^{-1}$) on barley yields and N uptake. The conventional tillage (CT) plots were cultivated in the fall and in the spring, with either a rototiller or a sweep-chisel cultivator. The zero tillage (ZT) plots were not cultivated, except for the disturbance caused by the hoe drill used each spring. The N fertilizer was surface urea, applied, but for the CT plots it was also incorporated into the soil (0 to 12 cm depth). Each year a blanket application of P, K, and S was applied to each treatment. A hoe-opener drill with a 0.23 m spacing between rows was used to sow spring barley at the rate of 100 kg ha^{-1}. When the crop was mature, a sample collected from a 2.3 m^2 area was harvested from each replicate of each treatment, dried at 60 °C, threshed, and the mass of grain and straw determined. After removing all plant biomass from the plots, straw was returned to the particular plots as shown on experimental plan. Weeds were controlled with herbicides or, if needed, by hand. Nitrogen in straw and grain was determined either by Kjeldahl method or by colorimetric analysis (Technicon Industrial Systems, 1977) of a H_2SO_4-H_2O_2-digested sample.

Results of this on-going investigation correspond to data obtained from 1980 through 1990. Statistical analyses were performed using procedures ANOVA, GLM, and REG in SAS.

RESULTS AND DISCUSSION

Grain Yield

The averaged annual yield of grain without N at the two sites was modestly greater on CT than ZT treatments, with differences ranging only from 213 to 446 kg ha^{-1} (Table 1). The average yield responses to the annual 56 kg ha^{-1} applications were especially large, ranging from 1,228 to 1,584 kg ha^{-1} among the three treatments which received N. At Site 1, the yield response to N was greatest when the straw was removed from the CT treatment, but at Site 2, the reponse to N was greatest with straw retention on CT. At both sites the yield with N was less with ZT than CT. The response of N uptake values followed different patterns at the two sites. At Site 1, N uptake on the treatment without N was greater with CT than with ZT. At this low-available N site, the CT treatment with removal of straw yielded highest in both grain and N uptake values. However, at the more fertile Site 2, the CT straw-returned treatment had the highest grain yield and N uptake.

Yields varied with years at both sites (Fig. 1), but there was positive response to applied N at each site and each year (Table 2). At Site 1, the grain yield on N fertilized CT without straw retention, compared to straw removal, was greater in the first of the 6 years (average of 478 kg ha^{-1}, significant in 3 of 6 years), while there was little average difference (40 kg ha^{-1}) in the last 5 years (Fig. 1). At Site 2, where the soil was high in soil organic matter content, the CT without straw yielded more grain than the CT with straw in the 2 first years (average of 412 kg ha^{-1}), but during the next 9 years the CT with straw treatment tended instead to have more grain yield (293 kg ha^{-1}) (Fig. 1, Table 2). That is, the ability of the two soils to accommodate straw without yield depression had developed it after six years (i.e. Site 1) and after two years (i.e. Site 2).

Table 1. Average of yield and N uptake over 11 years at two sites.

Treatment					
No.	Tillage	Straw	N	Grain yield	Plant N uptake
			kg ha^{-1}	kg ha^{-1}	kg ha^{-1}
			Site 1		
1	ZT	off	0	819	19.0
4	ZT	on	0	798	19.9
3	ZT	on	56	2092	49.9
5	CT	on	0	1011	24.0
8	CT	on	56	2394	50.5
2	CT	off	0	1021	22.6
10	CT	off	56	2588	58.4
$LSD_{0.05}$				173	3.6
			Site 2		
1	ZT	off	0	2069	43.7
4	ZT	on	0	1916	40.0
3	ZT	on	56	3240	75.6
5	CT	on	0	2170	45.5
8	CT	on	56	3754	91.5
2	CT	off	0	2362	49.7
10	CT	off	56	3590	92.1
$LSD_{0.05}$				168	3.5

Table 2. Statistical significance of grain yield contrasts.

Contrast	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
					Site 1						
CT vs ZT	ns†	*	ns	*	*	ns	*	*	ns	*	ns
Straw vs no straw	*	*	ns	ns	ns	ns	ns	ns	ns	ns	ns
No N vs N	*	*	*	*	*	*	*	*	*	*	*
					Site 2						
CT vs ZT	ns	ns	*	ns	ns	ns	*	*	*	ns	*
Straw vs no straw	*	*	ns	ns	ns	ns	ns	ns	ns	ns	ns
No N vs N	*	*	*	*	*	*	*	*	*	*	*

† ns = not significant; * = significant at $p < 0.05$.

Yields were often less with ZT than CT. At Site 1, ZT yields were same as CT yields in 6 instances, and the effect was nearly as pronounced at Site 2 (Fig. 1, Table 2). These 11-year results were generally similar to earlier 3-year results from two other north-central Alberta places (Nyborg and Malhi, 1989). Two other ZT and CT year-long experiments with ^{15}N labeled urea showed markedly less barley uptake of labeled urea with ZT than with CT, but the ^{15}N remaining in soil was much the same for the two treatments (Malhi and Nyborg, 1991).

N Uptake Estimation

Over 11 years, accumulated annual N uptake in grain + straw for each treatment at both sites showed an unusually close linear regression fit (Table 3). Evidently, three processes, depending on the treatment, contributed to the amount of annual N uptake. These were: the effect of tillage vs no tillage on net mineralization; N uptake as affected by fertilizer-use efficiency; and at Site 2, a carbon effect resulting in immobilization. Slope values of linear regressions of cumulative N uptake with time allowed us to use the values of Table 3 to build a simple explanatory model of the following form:

Table 3. Annual N uptake rate estimated by linear regression.

Treatment						
No.	Tillage	Straw	N	N uptake rate	Standard Error	R^2
				kg ha^{-1} year^{-1}	kg ha^{-1} year^{-1}	
				Site 1		
1	ZT	off	0	21.2	0.260	0.999
4	ZT	on	0	21.9	0.404	0.997
3	ZT	on	56	47.1	1.614	0.990
5	CT	on	0	26.3	0.211	0.999
8	CT	on	56	53.4	1.850	0.989
2	CT	off	0	24.8	0.255	0.999
10	CT	off	56	62.9	1.390	0.996
				Site 2		
1	ZT	off	0	47.3	0.463	0.999
4	ZT	on	0	41.5	0.407	0.999
3	ZT	on	56	74.2	0.889	0.999
5	CT	on	0	48.0	0.496	0.999
8	CT	on	56	92.5	1.329	0.998
2	CT	off	0	52.8	0.463	0.999
10	CT	off	56	91.8	1.000	0.999

$$Nupt_{(t)} = Nmin_{(t)} + \left(\frac{\Delta MI}{C}\right)_{(t)} \times \text{added C} + FUE_{(t)} \times FertN \qquad (1)$$

where,

(t) = Subscript for tillage method
$Nupt_{(t)}$ = Annual N uptake (kg ha^{-1} year^{-1})
$Nmin_{(t)}$ = Annual N mineralization (kg ha^{-1} year^{-1})

$\left(\frac{\Delta MI}{C}\right)_{(t)}$ = change in N mineralization - immobilization per unit carbon (kg ha^{-1} year^{-1})

$FUE_{(t)}$ = Fertilizer Use Efficiency

FertN = Annual addition of fertilizer N (kg ha^{-1} year^{-1})

$$GY = HI \times \frac{Nupt_{(t)}}{Nfrac} \tag{2}$$

where,

GY = Annual grain yield (kg ha^{-1} year^{-1})

HI = Harvest Index

Nfrac = Average N concentration in dry matter at harvest (kg kg^{-1})

Use of eqn. 1 allowed for the prediction of the average N uptake rate as affected by N mineralization, tillage-soil effect on N mineralization-N immobilization, fertilizer-use efficiency, and fertilizer-N added. Eqn. 2 was used to predict grain yield on the basis of N uptake, harvest index, and the fractional N concentration in dry matter. Predicted values using eqns. 1 and 2 correlated highly with observed values (Table 4).

Table 4. Linear regressions through origin of observed values versus those predicted using eqns. 1 and 2.

Site	Linear Equation	R^2
1	Observed N uptake (kg ha^{-1}) = 1.03 Predicted N uptake (kg ha^{-1})	0.948**
	Observed grain yield (kg ha^{-1}) = 1.34 Predicted grain yield (kg ha^{-1})	0.963**
2	Observed N uptake (kg ha^{-1}) = 1.04 Predicted N uptake (kg ha^{-1})	0.980**
	Observed grain yield (kg ha^{-1}) = 1.00 Predicted grain yield (kg ha^{-1})	0.907**

Examination of coefficients used in eqn. 1 allowed for the quantification of the various treatment effects on N uptake. At Site 1, N-mineralization on soil without straw addition averaged 21 and 25 kg ha^{-1} under ZT and CT, respectively. Addition of straw C promoted between 1 and 3 kg ha^{-1} of further N mineralization. Fertilizer-use efficiency averaged 41 % under ZT and 51 % under CT. At Site 2, N-mineralization on soil without straw addition averaged 47 and 53 kg ha^{-1} under ZT and CT, respectively. Addition of straw C promoted between 5 and 7 kg ha^{-1} of N immobilization. Fertilizer-use efficiency averaged 58 % under ZT and 70 % under CT.

Soil N Balance

In a previous paper, Nyborg et al. (1994) reported on the influence of these seven treatments on the concentration and mass of soil C and N of the 0-15 cm layer. With regard to soil N, they concluded that annual addition of fertilizer N and return of straw had resulted in a net increase of soil N in the 0-15 cm layer over a period of 11 years. Using the mass of soil N at the beginning of the experiment and the quantities of N added or removed from the system as fertilizer, grain, and straw, we calculated the theoretical mass of soil N to be found at the end of the experimental period as follows:

$$PredSoilN_{fin} = SoilN_{ini} - GrainN - StrawN + FertN \tag{3}$$

where,

$PredSoilN_{fin}$ = Predicted Soil N in 0-15 cm layer at the end of the experimental period (kg ha^{-1})

$SoilN_{ini}$ = Initial soil N in 0-15 cm layer at the beginning of the experimental period (kg ha^{-1})

GrainN = Mass of N removed in grain (kg ha^{-1})

StrawN = Mass of N removed in straw (kg ha^{-1})

Predicted values of soil N agreed closely with the observed values at the end of the experimental period ($ObsSoilN_{fin} = 1.09\ PredSoilN_{fin}$, $R^2 = 0.989^{**}$, $n = 14$). This equation tells us that it was possible to predict the range of soil N at the end of the experimental period (2580-7950 kg ha^{-1}) by accounting for the substractions and additions of N to the system in the form of fertilizer or plant compounds. In terms of output-input N balance, both CT and ZT treatments with addition of fertilizer N and retention of straw, were the only treatments with a net addition of N to soil over 11 years at Site 1 (40 and 117 kg ha^{-1}, respectively). At Site 2, the same was true only for the ZT treatment (29 kg ha^{-1}).

An extended conclusion to the agreement between observed and predicted soil N is that other losses and gains of N from and to the soil system had to be in balance, as in eqn. 4:

$$DenitN + LeachN + VolatN = NonSymbN + RainN + SubSoilN \quad (4)$$

where,

DenitN = N denitrification (kg ha^{-1})

LeachN = N leaching (kg ha^{-1})

VolatN = N volatilization (kg ha^{-1})

NonSymbN = Non-symbiotic N fixation (kg ha^{-1})

RainN = N added in precipitation (kg ha^{-1})

SubSoilN = Redistribution of soil N from subsurface horizon through plant uptake and decomposition (kg ha^{-1})

From the N losses we attribute N leaching and denitrification to be of importance. There are not accurate estimates of leaching losses for the soil systems under study. Previous work with ^{15}N, however, indicated that denitrification loss might be small from N fertilization in spring as compared to fall fertilization (Malhi and Nyborg, 1983). However, intensive rainfall soon after fertilization in spring might also induce substantial denitrification (Nyborg et al., 1990). A conservative estimate of annual N loss through denitrification is 20 kg ha^{-1} (Malhi and Nyborg, 1986; Nyborg et al., 1990; Laidlaw et al., 1993). Gains of N through precipitation have been estimated to be small, in the order of 1-2 kg ha^{-1}. This leads us to suggest that these surface soil layers might be also gaining N in the upper 0-15 cm layer from non-symbiotic N fixation, from subsurface soil, or both.

CONCLUSIONS

Immobilization of N by straw occurred during the first years of the experiment, but disappeared thereafter. This was confirmed by the small immobilization values indicated by the explanatory model. Zero tillage yields were slightly lower than the conventional tillage yields. Again, the explanatory equations indicated that FUE was slightly lower with zero than with conventional tillage. There was a slightly greater yield when straw was removed at the low organic matter Site

1, and the reverse at the high organic matter Site 2. That is, the long-term effect of straw removal or retention on continuously cropped barley yields was conditional on the site. Conventional tillage and zero tillage, with addition of fertilizer N and retention of straw, were the only treatments with a net addition of N to soil at Site 1. At Site 2, the same was true only for the zero tillage treatment.

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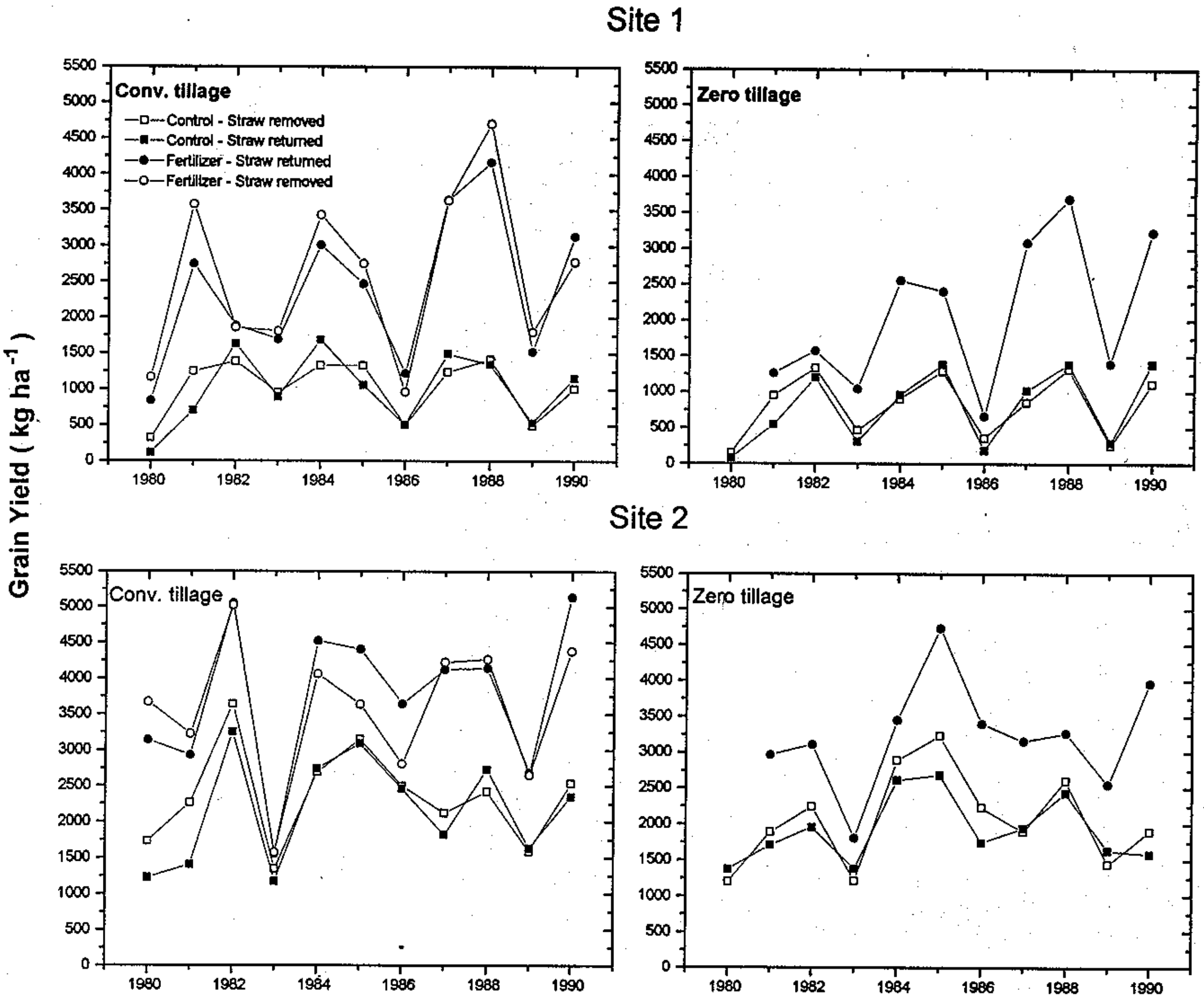

Fig. 1. Temporal changes of barley yields as affected by tillage method, straw disposal, and fertilizer N.

TRAFFIC AND TILLAGE SYSTEM EFFECTS ON N FERTILIZER UPTAKE AND YIELD FOR COTTON AND WHEAT

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ABSTRACT

Residual effects of soil compaction have led to interest in investigating the interactive effects of traffic and tillage systems on cotton and wheat production. A study was initiated utilizing a wide frame tractive vehicle to study the effects of traffic and tillage systems on a wheat-cotton double-crop system. The experimental design was a split-plot, with main plots as: 1) conventional traffic and 2) no-traffic. Subplots were tillage for cotton: 1) surface tillage without subsoiling, 2) surface tillage and in-row subsoiling, 3) surface tillage with one-time-only complete disruption of the tillage pan, 4) no surface tillage, but planted with in-row subsoiling (strip-till). All tillage treatments were applied to the cotton and residual effects were observed in the wheat. Fertilizer applications were made as ^{15}N-depleted NH_4NO_3 to both crops. In 1990, under extreme drought conditions, traffic increased seed cotton yield 10%, but tillage systems had no effect. In 1991, with above normal rainfall conditions, traffic decreased seed cotton yield 13%. In this year, strip-till increased cotton biomass production and significantly reduced the negative impact of traffic on cotton plant N uptake. No traffic resulted in a 10-20% increase in fertilizer-N efficiency in the wheat. Surface tillage of cotton without any subsoiling increased nitrate leaching in the wheat. While fertilizer application in cotton had no effect on N uptake under wheat, both traffic and tillage systems affected N recovery in the cotton plant/soil system from fertilizer applied to the wheat.

INTRODUCTION

Soil compaction has been recognized as a major crop production problem (1), especially on sandy coastal plain soils of the southeastern USA (2, 3). Reduced N uptake caused by physical impedance and stress on plant roots (4) and alterations of soil N transformation processes (5) have been attributed to soil compaction. For example, Torbert and Wood (5) reported that compaction-induced alteration of soil pore spaces promoted microsite anaerobiosis, resulting in increased denitrification. The effect of soil compaction caused by wheel traffic may be very persistent, especially in the subsoil (3). Voorhees et al. (6) found that increased bulk density and reduced hydraulic conductivity caused by traffic still persisted after 4 years, while Blake et al. (7) found that subsoil compaction persisted 9 years after treatment application. Because of the persistent nature of soil compaction, residual effects may be important to N cycling in the plant/soil system. The objective of this study was to examine the residual effects of tillage and traffic on crop production and fertilizer N utilization on succeeding crops in double-cropping systems.

MATERIALS AND METHODS

A field study was initiated in June of 1987 at the Alabama Agricultural Experiment Station's E.V. Smith Research Center in east-central Alabama, USA. The soil is a Cahaba-Wickham-Bassfield sandy loam complex (thermic Typic Hapludults). Cation exchange capacity (C.E.C.) and organic matter content for the test site averaged 6.31 $cmol_c\ kg^{-1}$ and 11.9 $g\ kg^{-1}$, respectively. The site naturally has a well developed 8- to 15-cm thick hardpan beginning at a depth ranging from 20- to 30-cm deep.

This study utilized a wide frame tractive vehicle (WFTV) designed to allow for 6.1-m wide untrafficked research plots which allowed for the use of various tillage systems in a zero-traffic environment. Cotton was grown in a double-cropping system with wheat. Fig. 1 depicts a time line indicating the approximate times for farm operations, treatment applications, and data collection in the study.

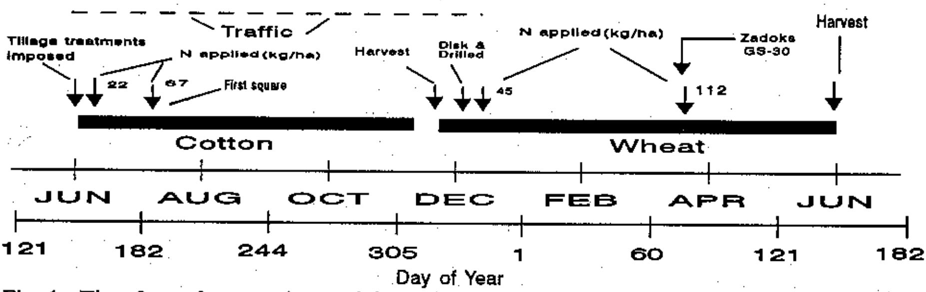

Fig. 1. Time-frame for operations and data collection in cotton-wheat double-cropping experiment in 1990 and 1991.

The experimental design was a split-plot with three replications. Main plots were: 1) conventional traffic, and 2) no-traffic. Main plots were split into subplots of tillage systems applied to cotton: 1) complete surface tillage without subsoiling (surface), 2) complete surface tillage and annual in-row subsoiling to 40-cm depth (subsoil), 3) complete surface tillage with one-time only complete disruption of tillage pan (complete), and 4) no surface tillage but planted with in-row subsoiling (strip-till). Complete surface tillage consisted of disking, chisel plowing (20-cm depth), disking, and field cultivation. The one-time only complete disruption of the tillage pan was accomplished by subsoiling to a 50-cm depth on 25-cm centers, using a V-ripper in November, 1987. The strip-tilled cotton was planted into wheat residue with an in-row subsoiler planter. After the cotton was harvested, all plots were disked and planted to wheat with a 3-m width drill having 10-cm drill spacing. To assure uniform tillage equipment operation, all operations were performed with the WFTV. On the conventionally trafficked plots, a 4.6 Mg tractor was driven through the plots to simulate traffic that would have been applied using four row equipment for each operation.

Ammonium nitrate was broadcast applied for both crops. The rate for cotton was 22 kg N ha^{-1} at planting and 67 kg N ha^{-1} at first square. The rate for wheat was 45 kg N ha^{-1} at planting and 112 kg N ha^{-1} following winter dormancy at Zadoks GS-30. During 1990-91, ^{15}N-depleted NH_4NO_3 was applied to a 2.4- by 3-m microplot inside each tillage/traffic plot in both crops. To assess the amount of fertilizer N carried over into the subsequent crop, soil cores were taken from microplots of the previous crop at harvest in both cotton and wheat.

At physiological maturity aboveground plant samples and soil cores were collected from all microplots for both crops. Soil cores were sectioned into 0-15, 15-30, 30-60, and 60-90-cm depth increments. The total N content and isotope ratios were determined on both plant and soil samples. Soil solution samplers (90-cm depth) were installed in each wheat microplot and sampled weekly to monitor NO_3-N movement below the rooting zone. Monitoring of soil solution samples began shortly before the second fertilizer N (112 kg ha^{-1}) application to the wheat and continued until harvest. This period was chosen because weather patterns in Alabama make this period the most vulnerable to nitrate leaching as well as supplying adequate soil moisture conditions for solution sampling. The term *total fertilizer N recovery* is used to reflect fertilizer N recovered in both plant and soil. Statistical analysis of data was performed using ANOVA procedure and means were separated using least significant difference (LSD) at 10% probability level.

RESULTS AND DISCUSSION

Cotton

The effect of tillage systems on cotton production was weather dependent. In 1990 (a dry growing season), traffic had a positive effect on cotton production. While total cotton biomass was not significantly affected by traffic, both seed and lint production were lower in the no-traffic treatment as compared to conventional traffic, with 1500 vs. 1360 kg seed cotton ha^{-1} produced for traffic and no-traffic, respectively. This is consistent with results reported for other crops under severe environmental conditions (2, 6). In this year, no significant difference was detected between tillage systems.

In 1991 with above normal rainfall, traffic reduced seed cotton yield compared to no-traffic, with 2301 vs. 2607 kg seed cotton ha^{-1} for traffic and no-traffic, respectively. In this year, tillage system affected cotton yield components, with strip-till significantly increasing seed cotton, stalk, and total biomass compared to the other tillage treatments (Table 1).

Table 1 Effect of tillage system on yield components of cotton, 1991†.

	Tillage System			
	Complete	Strip-till	Subsoil	Surface-only
	Yield (kg ha^{-1})			
Stalk	2240 b	2873 a	2513 b	2331 b
Seed	1409 b	1625 a	1380 b	1437 b
Lint	952 b	1085 a	934 b	992 ab
Biomass	4601 b	5583 a	4827 b	4760 b

† Values within a row followed by the same letter do not differ significantly (0.10 level).

A significant traffic x tillage interaction occurred for cotton N uptake (Table 2). The detrimental effect of traffic on N uptake was reduced in the strip-till treatment compared to the other tillage treatments with a plant fertilizer N uptake efficiency in strip-till of 28.4% compared to 20.7% for surface-only within the traffic treatments (calculated from

^{15}N in plant/^{15}N applied). This effect is most likely from reduced soil compaction in the strip-till as a result of both a reduction in the number of traffic trips needed for strip-till as well as an increase in the bearing capacity of soil when conservation-tillage practices are used (2). These conclusions are consistent with penetrometer and soil bulk density data indicating that soil strength measurements for strip-till plots were reduced compared to the other tillage treatments (8). This indicates that the detrimental effect of traffic on N efficiency may be reduced if conservation-tillage practices are used in these sandy coastal plain soils.

Table 2. Traffic and tillage system effect on cotton plant total N uptake, 1991.

	No-Traffic	Traffic
	— Total N Uptake (kg ha^{-1}) —	
Traffic		
Complete	121	112
Strip-till	134	129
Subsoil	128	110
Surface	132	107
$LSD_{0.10\ (any\ two\ means)} = 21.2$		
$LSD_{0.10\ (within\ traffic)} = 10.8$		

Significant treatment effects were observed in the amount of recovered N in the cotton plant/soil system attributed to fertilizer N applied to the wheat. In both years (1990 and 1991), strip-till significantly increased the amount of wheat fertilizer N remaining in soil but had no effect on cotton plant N that could be attributed to fertilizer applied to wheat (Table 3). This was likely due to immobilization of N in wheat residue in this conservation-tillage system. The total amount of wheat fertilizer N recovered in the cotton soil/plant system with the strip-till treatment was 26 and 47% of that applied in 1990 and 1991, respectively.

Table 3 Traffic and tillage system effects on residual wheat fertilizer N in the cotton plant and remaining in soil.

	1990		1991	
	Plant	Soil	Plant	Soil
	—— Fertilizer N applied to Wheat (kg ha^{-1}) ——			
Tillage				
Complete	6	15	17	35
Strip-till	6	35	19	55
Subsoil	4	14	18	38
Surface	6	15	19	37
$LSD_{0.10}$	ns	9	ns	12
Traffic				
Traffic	8	23	20	44
No-Traffic	4	17	16	39
$LSD_{0.10}$	1	ns	3	ns

Traffic significantly affected N uptake that could be attributed to the wheat fertilizer N application, but was a product of plant response to the traffic. As was seen in total N uptake, traffic increased cotton uptake of wheat fertilizer N in 1990 and decreased wheat fertilizer N uptake in 1991. An average of 6 and 15% of total N taken up by the cotton plant could be attributed to fertilizer N applied in the wheat in 1990 and 1991, respectively.

Wheat

In 1990, traffic reduced wheat yields from 3427 to 2981 kg ha^{-1} and total recovery of fertilizer N in the plant/soil system was decreased with traffic from 87.8 to 73.2 kg N ha^{-1} compared to no traffic. While the tillage system used in the previous cotton crop had no effect on wheat yields in this year, strip-till of cotton increased total fertilizer N recovery 20% in the wheat compared to other tillage systems (Table 4). These same trends were observed for tillage and traffic treatments in 1991, but disease pressure on the wheat resulted in no significant differences.

Table 4 Effect of previous cotton crop tillage system on fate of fertilizer N at wheat harvest calculated from ^{15}N data in 1990†.

Fertilizer N	Tillage System: Complete	Strip-till	Subsoil	Surface
	Fertilizer N (kg ha^{-1})			
Total plant uptake	54 a	58 a	51 a	51 a
Remaining in soil	22 b	33 a	28 ab	25 b
Total recovered	76 b	91 a	79 ab	76 b

† Values within a row followed by the same letter do not differ significantly (0.10 level) averaged over traffic treatments.

Tillage treatments applied to the cotton impacted NO_3-N concentration below the rooting zone of wheat (Fig. 2). Surface tillage without subsoiling in the cotton resulted in significantly higher NO_3-N concentration at several points during both years. Because this is the only tillage treatment that did not receive some form of deep tillage, it is believed that compaction-induced root restriction of the wheat resulted in reduced root exploration and N uptake allowing more NO_3-N to move through the soil profile. Likewise, the subsoiled treatments could have had an increased abundance of deep roots to scavenge for nitrate moving deeper into the soil profile. Fertilizer N applied to cotton had little effect on N in the plant/soil system of the wheat, with no significant treatment effects observed. An average of 5 kg N ha^{-1} in the plant and 10 kg N ha^{-1} in soil could be attributed to the fertilizer applied to the cotton crop.

CONCLUSION

Results from this study indicate that weather conditions greatly affected cotton response to tillage, but the conservation-tillage system, strip-till, produced the most consistent yield levels of the tillage systems compared during the study. With adequate moisture for plant growth, traffic-induced compaction negatively impacted cotton plant growth and N uptake, however, the negative impact of traffic was reduced with the use of the conservation-tillage system (strip-till).

In this study, evidence suggests that improved soil physical conditions and consequent improved rooting by the succeeding wheat crop was the major factor in reducing N losses and increasing fertilizer N recovery in the plant-soil system. Thus, the tillage system used for production of one crop may have lasting effects on the soil system and the beneficial effects of a conservation tillage system used for one crop may extend to subsequent crops.

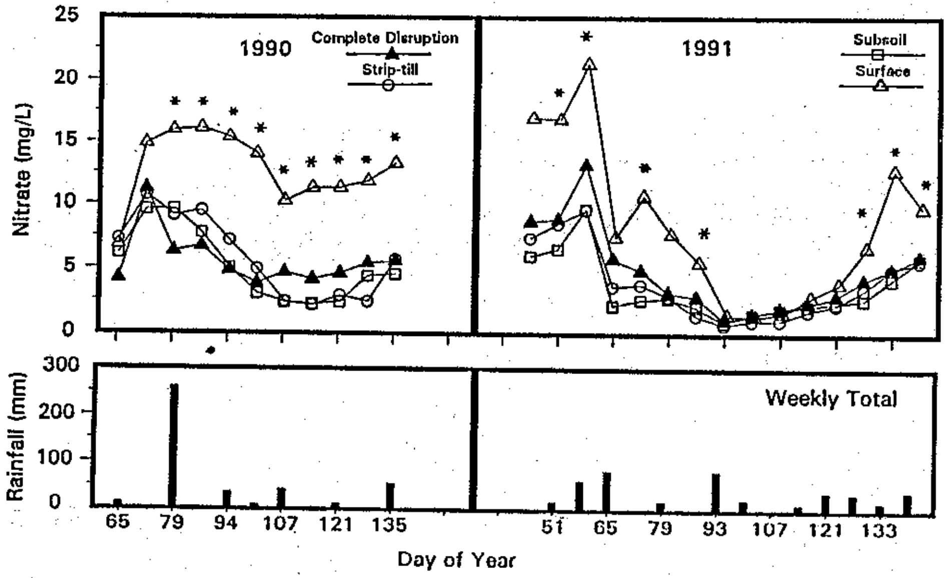

Fig. 2. Soil solution NO_3-N for tillage treatments imposed on previous cotton crop, during 1990 and 1991 wheat growing season. Asterisk denotes significant differences.

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TILLAGE STUDIES FOR SUSTAINABLE CROP PRODUCTION IN THE SEMI-ARID TROPICS OF NORTHERN AUSTRALIA

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ABSTRACT

The long term effects of tillage on crop yields and soil nutrients under no-till (NT) and conventional tillage (CT) treatments were evaluated between 1984-1993 on an Alfisol (Rhodic Paleustalf) in the Douglas Daly region of northern Australia. Average yields of five maize, five soybean and one sorghum crop under NT were 33,31 and 12% higher, respectively,than under CT. Organic carbon, total nitrogen, available Ca,Mg,Zn,Cu and P in the surface (0-5cm) soil after 8 years of cropping were, respectively, 67,48,20,57,96,38 and 7% higher under NT than under CT. No differences were observed in soil pH and available K, due to tillage effects.

INTRODUCTION

Farming systems in the semi-arid tropics of northern Australia are highly mechanised and capital intensive. Economic and environmental sustainability of these systems depends on how well the soil can be protected from degradation. Energy and soil management practices are key to the development of a sustainable farming system that can be achieved through the selection of suitable pastures and crops and their rotation under a conservation tillage system. The soils of the Douglas Daly Region are inherently low in carbon and mineral nutrients and intensive cultivation practices has already caused significant deterioration of soil structure. On these soils (Alfisols prone to crusting and erosion) a no-till system is proving more effective than conventional tillage for soil and water conservation and the production of grain crops and pastures (McCown et al.1980, 1985; Thiagalingam et al 1991 a and b). Anderson (1986) reported significant yield increases of 17 and 24% under no-till compared to conventional tillage in three out of four locations. Blevins et al 1971, Triplett et al 1968, Thiagalingam et al 1991(a) indicated that grain yields were higher in years with poor rainfall under the NT system compared to the CT system. McCowan et al (1985) found that mulch retention under no-till increased maize yield by 20%. This study was initiated to evaluate the long-term effects of tillage and rotation on soil properties and crop yields.

MATERIALS AND METHODS

In the 1984-85 wet season a maize-soybean rotation and tillage experiment was established at the Douglas Daly Research Farm (DDRF) in the northern Territory Australia (13°51'S and 131°12'E). The climate is monsoonal with a distinct wet and dry season; 90% of the annual rainfall is recorded between November and March (Williams et al 1985). The soil is Tippera clay loam (a Rhodic Paleustalf) which has a strong hard setting surface and a pH of 6.8. The first phase of the experiment was completed in the 1987-88 wet season. Details of the experimental layout and cultural practices are given in Thiagalingam et al 1991 (a). In the second phase, the tillage treatments were maintained and the following crops sown annually in sequence (a) sorghum 1988-89 (b) maize 1989-90 (c) soybean 1990-91 (d) maize 1991-92 (e) soybeans 1992-93. The experiment was fertilized annually with muriate of potash and single superphosphate (with Zn, Cu, Mo) providing 25kg K, 30kg P, 30kg S, 5kg Zn, 5kg Cu and 0.2 kg Mo per hectare. In addition the cereal crops received an additional application of nitrogen of up to 80kg N/ha as urea. Prior to sowing of crops,the no-till areas were sprayed with glyphosate at 2 liters per hectare. Due to management problems maize yields in 1989-90 and soybean yield in 1990-91 soybean crops were harvested but yields were not recorded separately for the tillage treatments.

Soil samples, 0-5, 5-15 and 15-30 cm depth were collected after 8 years (1991-1992 wet season) and analysed for pH, organic carbon, total N, available P, Ca, Mg, K, Zn and Cu. In the 1992-93 season, two soybean varieties, Leichhardt and Buchanan were sown in the NT and CT plots in a split-plot design. Establishment counts were made 12 days after sowing, leaf samples (youngest fully expanded) were collected at 49 days after sowing and analysed for N, P, K, Ca, Mg, S, Zn, Cu,Mn, B and Fe, and grain yields were measured at harvest.

RESULTS AND DISCUSSION

Effect of tillage on crop yield

Average yields for five maize, five soybean and one sorghum crop over nine years (1985-1993) were respectively, 33, 31 and 12% higher under NT than under CT (Table 1).

Table 1: Average yields of maize, soybean and sorghum under NT and CT(t/ha)

Crop	NT	CT	Yield increase(%)
Maize (5)	3.66	2.75	33
Soybean (5)	2.24	1.71	31
sorghum (1)	3.25	2.90	12

() Number of seasons

In seasons with prolonged dry spells or very low total rainfall yield under NT exceeded that under CT by up to 130% (Thiagalingam et al 1991a). The yield of the two soybean varieties Leichhardt and Buchanan sown in the 1992-93 season was significantly higher under NT than under CT (Table 2). The combined yields of both varieties were 215% higher under NT than under CT. These yield increases were attributed to the higher plant population under NT compared with CT (Table 2). Dick et al 1991 reported yield advantages associated with NT even after 18 years of cropping on a well drained soil and lower yields on a poorly drained soil without rotation.In our studies a positive response to NT was obtained after nine years of cropping. In both soybean varieties the seed protein content was higher under NT than under CT.

Table 2: Effect of tillage on soybean established plant population, grain yield and protein content

Soybean variety	Plants /ha NT	Plants /ha CT	Yield (kg/ha) NT	Yield (kg/ha) CT	Seed Protein (%) NT	Seed Protein (%) CT
Buchanan	556667	211792	1760	682	41	40
Leichhardt	605285	186331	1896	477	46	42
CV %	17.06		25.37		4.479	
LSD 5% (tillage)	94020		432		2.659	

Effect of tillage on soybean leaf nutrient concentration (1992-93)

Nutrient concentrations in soybean leaves at 49 days after sowing are presented in Table 3. The results indicate a significant increase in nitrogen concentration with significantly lower Mn and Fe concentrations under NT compared with CT. The nitrogen concentration under NT was 45% higher than CT irrespective of the varietal differences indicating that NT treatments provided a favourable environment for nitrogen fixation than CT. The average Mn concentration of 290ppm found in the CT treatment is greater than the toxic level of 160ppm for similar leaf age given by Reuter and Robinson (1986). The higher concentration of Mn and Fe found under conventional tillage may be due to compaction and water logging resulting in the reduction of Mn and Fe causing higher solubility and uptake. The high levels of Mn and Fe may interfere with nodule activity and reduce N-fixation. No significant differences were found with P, K, Ca, Mg, S, Zn, Cu and B between the two tillage treatments.

Table 3: Nutrient concentration in soybean leaves (youngest fully expanded) at 49 days after sowing (1992-93)

Til	Var	N %	P %	K %	Ca %	Mg %	S %	Zn ppm	Cu ppm	Mn ppm	B ppm	Fe ppm
NT	B	4.2	.48	2.9	.93	.44	.29	58	12	127	54	102
	L	4.3	.50	3.1	.96	.38	.28	66	15	103	52	104
	av	4.3	.49	3.0	.95	.41	.29	62	14	115	53	103
CT	B	3.2	.45	2.8	.97	.42	.28	69	12	337	53	300
	L	2.6	.44	2.9	.97	.36	.25	68	13	243	57	142
	av	2.9	.45	2.9	.97	.39	.27	69	13	290	55	221
LSD 5%	Til	.43	NS	NS	NS	NS	NS	NS	NS	83	NS	106

Til=Tillage
Var=Variety
B =Buchanan
L =Leichhardt
Av =Average

Long-term effects of tillage on soil chemical properties

Long-term effects of tillage on some soil chemical properties at 0-5, 5-15 and 15-30 cm depths are presented in Table 4. Under NT, organic carbon and total nitrogen at the 0-5 cm depth were 60 and 48% higher respectively than under CT after 8 years of cropping. Similar observations have been reported by Woods and Edwards (1992); Lal (1976); Dick (1983) and Dalal (1989). This significantly lower organic carbon under CT may be due to a higher rate of breakdown of crop residues under this regime in the semi-arid tropical environment. In contrast the organic carbon and total nitrogen contents at 0-15 and 15-30cm depths were unaffected by tillage regime.

Table 4: Soil chemical properties as affected by tillage and depth after 8 years of cropping

Til	Dep cm	pH	C %	N %	P ppm	K ppm	Ca ppm	Mg ppm	Zn ppm	Cu ppm
NT	0-5	6.1	1.05	.123	30	205	671	129	5.3	5.8
	5-15	6.2	0.69	.077	14	172	568	85	1.0	3.3
	15-30	6.1	0.36	.053	11	131	449	83	1.0	2.6
CT	0-5	6.1	0.63	.083	28	217	557	82	2.7	4.2
	5-15	6.2	0.61	.073	22	171	566	82	1.7	3.9
	15-30	6.1	0.35	.057	18	143	473	80	1.0	2.4

Til=Tillage
Dep=Depth

Studies by Hargrove (1985) showed a greater concentration of P in the surface soil under NT as compared with CT. In our studies tillage regime had no significant effection P concentration in the surface soil, although P levels tended to be higher at the lower depths under CT compared with NT. This may be due to low plant population in CT and lower utilization of P by both maize and soybeans. In general the levels of Ca, Mg, Zn and Cu were 20, 57, 96 and 38% higher under NT compared with CT but the differences were not significant. Long-term studies on Alfisols have demonstrated that applied nutrients remained near the surface due to lack of physical mixing, less leaching of some nutrients under NT compared with CT (Hargrove, 1985; Eckert 1991; Woods and Edwards 1992 and Dick 1983). There was no change in soil pH between the two tillage systems except that the original soil pH has dropped from 6.8 to 6.1 in both the systems.

CONCLUSIONS

The long-term tillage studies show that under our environment and in particular on the Tippera clay loam, higher yields can be maintained under NT. It can also be concluded that soil organic carbon, total nitrogen and other available nutrients in the surface increase under NT compared with CT and provide an environment for structural stability.

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MULCH AS A PART OF TILLAGE SYSTEMS IN THE PACIFIC REGION

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ABSTRACT

Sustainable tillage systems mean different things to different people. In Pacific Agriculture sustainability can mean managing steep slopes in high rainfall areas, using flat land but using it continually, or using shifting cultivation techniques. Many systems use minimum cultivation and rely on planting holes while mulching is practised to some extent within tillage systems and for long term sustainability is a technique which needs to be understood in the South Pacific environment. A number of experiments have been done which indicate that mulching does have some benefit on crop growth in this Region and there is an indication that chemical properties were modified. The possible mechanism for the change in crop growth and chemical properties is temperature. Soil temperature was measured in an experiment with five treatments (one control and four types of mulch). Chemical properties and biological activity were measured which indicated that soil temperature could be implicated in these changes. Yield of taro varied as a result of these temperature and chemical changes and mulch was found to have a positive effect on crop growth.

INTRODUCTION

Tillage systems in the Pacific Islands are variable(1). Much emphasis is now being placed on studying traditional and sustainable systems which range from managing steep slopes in high rainfall areas to using flat land and in many cases land is prepared by hand (i.e. minimum tillage systems). In many traditional gardens the major crop is taro *(Colocasia esculenta (L.) Scholl)* (dalo) which has an approximate 9 month growing period. Where taro is grown the system is often monocropped planting taking place in planting holes although some traditional gardens are multicropped. Crops other than taro may be substituted in some countries but taro plays a major role in the diet of the peoples in the South Pacific. Not all crops produced are for home consumption and location of markets and potential export facilities have some effect on the crops grown.

Taro being a long standing crop in the field needs an adequate supply of water for growth and although rainfall is high in some of the Pacific Islands up to 5000 mm in many places there is still a seasonality and techniques that may conserve water can also be a distinct advantage. The introduction of water conservation measures such as mulching can therefore be an important and integral part of Pacific Tillage Systems. Mulches have been used in some situations and reference to use of mulches go back a number of years and indeed circumstantial evidence indicates mulching has been a part of the potential agriculture systems in the region for some time.

Reasons for the use of mulches in agricultural systems are multifaceted and have been known to reduce soil erosion and run-off losses (2); decrease soil temperature (3, 4, 5) improve soil water storage (2, 3); increase infiltration rates (6) and increase the availability of soil phosphorus (2). Mulching also increases soil organic matter levels considerably (5, 7). Studies carried out in Western Samoa show that this practice promoted the growth of corn - (*zea mays L*) (2) and taro (5, 8). Different mulches which have been used decompose at different rates for example dadap *(erythrina indica)* and gliricidia *(gliricidia sepium)* when applied to the soil usually decompose more rapidly than grass *(panicum maximum)* and *paraserianthes falcataria* (5).

In the early 1980s (3, 8) the effect of mulch on the growth of taro (8) and corn was studied (3). Taro yield was found to increase with mulch (8) while with corn there was a large but non significant increase in yield from mulch with fertilizer application (8). Soil temperatures under mulch (3) were reduced some 2°C suggesting that temperature could be a critical factor.

As the experiment with the taro (8) did not have any records of temperature it was decided that it was appropriate to look at mulching of taro with different types of mulch; to measure temperature; soil water potential and study biological and chemical activity.

MATERIALS AND METHODS

An experiment was established in Western Samoa at the School of Agriculture of the University of the South Pacific, Alafua Campus on a Latosol (Moamoa stony clay) which is an Oxic Humitropept (8).

Taro *(Colocasia esculenta (L.) Schott)* tops of the cultivar Niue were planted at a spacing of 70 cm x 70 cm in 15 plots (5.6m x 5.6m) in a randomized complete block design. There were 49 plants in each plot. Five treatments were used; control - Treatment 1; dadap *(Erythrina indica)* - Treatment 2; gliricidia *(Gliricidia sepium)* - Treatment 3; *(Paraserianthes falcataria)* - Treatment 4; grass *(Panicum maximum)* -Treatment 5; the mulch being applied as 30 t/ha on a fresh weight basis at the time of planting the taro (7 May, 1991). Each treatment was replicated three times.

Measurements taken were soil temperature with thermistors at 2.5 cm and 15 cm at two locations in all five treatments at 30 minutes intervals for varying periods during the experiment; soil water potential with tensiometers at 15 cm in all plots at 0800 hr each day for 3 months after planting until mid August. Soil samples were collected for analysis of cation exchange capacity; organic matter level; available nitrogen; phosphorus and potassium. Also determined was carbon dioxide production. In this paper only results for organic matter and phosphorus levels and carbon dioxide production are discussed.

The crop was harvested in October and yield of taro corms both fresh and dry weights were determined.

RESULTS AND DISCUSSION

Yield of Taro

This section is presented first because the other data will refer back to the yield of the crop. Yield of the taro in this case was just the corm and is presented for the five treatments in Table 1 with fresh and dry weights in (t/ha). (In some experiments the corm plus 30 cm of stem is used to calculate resulting in higher values). There is an obvious effect of mulch on the yield as all the mulched plots have higher yields than the control, three of them significantly so. The effect is variable depending on the type of mulch. In the following discussion with the results various factors will be suggested as to the reason for these differences.

Table 1: Average yield of taro in the control and mulched plots (t/ha)

Treatments		Fresh Weight	Dry Weight
Control	1	1.4^{a}	0.5^{a}
Dadap	2	3.6^{b}	1.4^{b}
Gliricidia	3	2.5^{ab}	0.9^{ab}
Paraserianthes	4	3.4^{b}	1.3^{b}
Grass	5	3.3^{b}	1.2^{b}
LSD 5%		1.6	0.6

Soil Temperature

The daily variation of soil temperature is presented for two days 10 May near the start of the growing season and some 2½ months later 28 July when the crop has fully extended leaves Figure 1. It is clear that mulch results in lower temperature during the day and higher temperature at night at the start of the season. However in July the differences in temperature are less for three of the mulched treatments picking up the effect of crop canopy while grass has temperatures lower than the control at all times during the day. This is not an unusual feature of dense cropping and dense mulch.

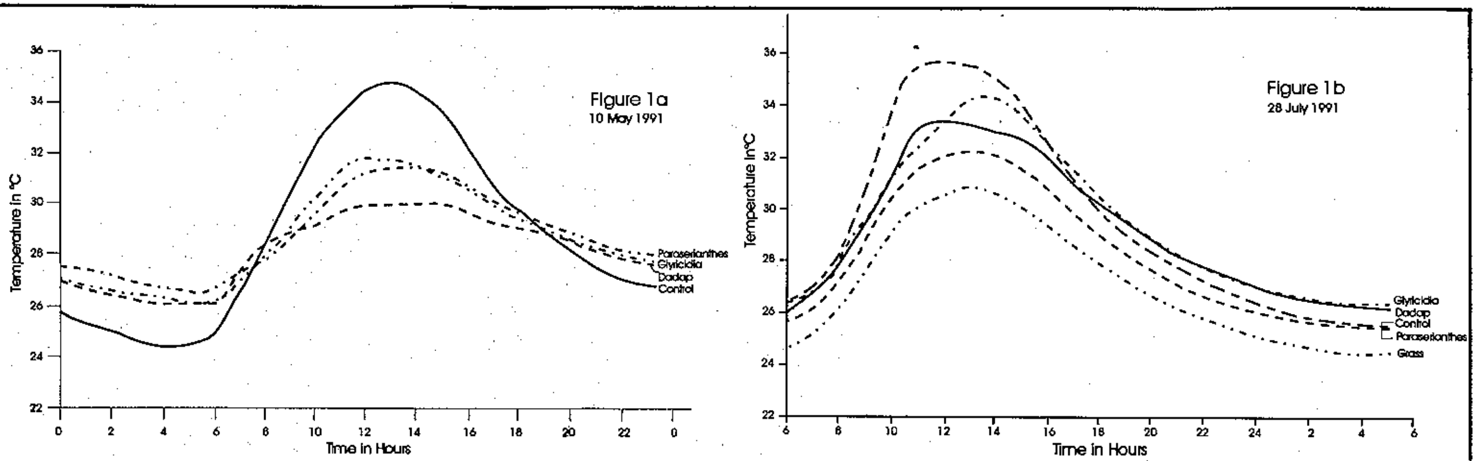
There is no firm data on what is the optimum temperature for growth of taro however figures of between 26 - 30°C are suggested. If that is the case then all treatments will have some limitation except perhaps the grass covered plots where e.g. in July the minimum is 24.5°C and the maximum 30.8°C. When looking at yield it is the plot mulched with dadap which has the highest yield and although the differences between it and the grass and *Paraserianithes* are small the temperature is about midway between the hottest are coolest plots. In Figure 2 average temperatures are calculated over a two week period in May and a further two week period in July and are compared with yield and indicate that there could be an optimum temperature which would need to be investigated further. It is possible too much mulch could be detrimental. In some ways these results pose as many questions as they answer.

Soil Water Potential

During the period through to the 10 August only for a short period towards the end of July did the soil water potential at 15 cm drop to close to -100kPa, the control being -95kPa (tensiometers inaccurate at this reading) while in the mulched treatments this figure was about -70kPa. At all other periods the water potential was greater than - 50kPa and in the mulched plots always greater than -30kPa. The difference between the mulched treatments were always small and on average the difference is < -3kPa between treatments and the control plot was always drier than the mulched plots. This small difference between mulched plots is unlikely to account for any differences in yield except for the control plots.

Organic Matter

Organic matter levels vary with time and treatment, Table 2 although they are equal at the start of the experiment. All the mulched treatments have greater amounts of organic matter than the control plot although no statistical analysis has been done. This is expected on two counts i.e. more organic material can be added to the soil from mulch but the lower maximum temperatures



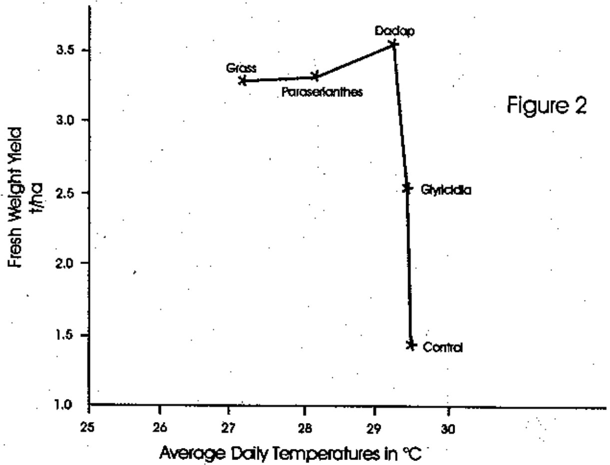


Figure 1: Daily Temperature variation under various mulch Treatments

Figure 2: Fresh weight yield versus average daily temperature

Table 2: Organic matter content of soils (%) in the control and mulched plot

Date	Treatments				
	1	2	3	4	5
20 May	4.06	4.29	4.35	4.11	4.18
4 June	4.12	4.62	4.42	5.02	5.06
18 June	4.07	4.48	4.69	5.21	5.18
3 July	4.10	4.79	5.47	5.42	5.14
17 July	4.64	5.24	5.68	5.76	5.74

Treatment 1 - Control; 2- Dadap; 3 - Gliricidia; 4 - Paraserianthes; 5 - Grass

will result is less breakdown of the organic material. The increases in organic matter are not necessarily consistent with the range of increases in yield. For example the plot with highest yield dadap has the smallest increase in organic matter over the control and average temperature as already indicated midway between the highest and lowest.

Available Phosphorus

Table 3: Available phosphorus of soils (ppm) in the control and mulched plots

Date	Treatments*				
	1	2	3	4	5
20 May	2.12	2.09	2.63	2.72	2.80
4 June	2.23	2.65	2.84	2.95	2.81
18 June	2.32	2.85	2.98	3.12	2.91
3 July	2.36	3.12	3.25	3.21	3.01
17 July	2.46	3.35	3.56	3.14	3.10

*** See Table 2 for legend.**

In Table 3 the information for available phosphorus is given (Truog method). Once again the plots with mulch have an indication of higher fertility i.e. available phosphorus is higher in the mulched plots. The pattern for the increase does not follow the same as yield or the same as the organic matter levels but again mulch is an important component in increasing fertility. Most chemical reactions are temperature dependent and the reduction in high temperatures could slow the reaction of phosphorus and thus reduce losses. It is significant that in all plots there is an increase in available phosphorus but that it is only dadap and gliricidia that levels have increased close to 1ppm. In the paraserianthes and grass plots the increase in phosphorus is similar to that in the control plot.

Biological Activity

Biological activity of the soil was measured as grams of CO_2/g soil/4 days. These figures are high. It would appear there is greater activity in the case of the plots with mulch than the control plot. Biological activity is usually temperature dependent and as temperatures rise the activity increases

Table 4: Biological activity of soils (indicated by g CO_2/g soil/4 days) in the control and mulched plots

Date	Treatments				
	1	2	3	4	5
18 June	34.4	41.2	37.3	38.6	38.4
2 July	25.7	31.6	37.8	38.7	40.7
16 July	35.8	39.2	43.8	44.1	41.4
30 July	37.4	43.3	45.0	43.3	50.3
14 August	34.8	41.6	43.8	42.3	46.1

See Table 2 for legend

(9). However in this case the greatest activity occurs in the mulched plots which have lower average temperatures and lower maximum temperatures (see Figure 1). The implication of this is that although temperature usually increases activity there could be an upper limit. The effect of the mulch too will encourage various organisms to be active. It is interesting to note that on 18 June the values of biological activity follow the same order as yield i.e. the lowest level of activity is equivalent to the lowest yield and highest activity relates to highest yield. This equality does not apply again during the period in which measurements are made.

Mulch therefore has a positive effect on yield of taro by modifying various soil parameters which have enhanced the growth of taro.

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NO-TILLAGE SYSTEM WITH WHOLE CORNSTALKS AND HALF-MULCHING FOR CORN (Zea Mays) PRODUCTION IN THE SEMI-ARID REGION

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ABSTRACT

In a 3-year study at 5 locations of Shanxi province, corn was grown on plots treated with NTHM, NTFM, NT, and CT. Soil temperature, soil moisture, plant height and weight, and grain yield were obtained. Average corn grain yield from NTHM or NTFM during the 3-year period at 5 locations was comparable to 34.3% above yields from NT or CT. Soil moisture measurements indicated that NTHM and NTFM were highly effective in reducing evaporation. Soil temperature at 0~20 cm depth was lower throughout the growing season under NTHM and NTFM, but compared to NTFM, NTHM might increase soil temperature 1.1 °C during the growing season. The low temperatures under NTHM and NTFM were associated with a temporary depression of growth during the early growing season. A significant increase in growth of NTHM or NTFM over NT or CT corn, beginning in late June, was attributed to the greater moisture under NTHM or NTFM during the period of high plant requirements.

INTROCUCTION

Modern reduce- and no-tillage system was initiated in the 1960's and has since been used increasingly in recent 20 years. For 1990, no-tillage production of maize, wheat, rape, soybeans, peanut, and rice in China has been estimated at 12,333,000 ha. In the loess plateau of China, inadequate amounts of soil moisture during the growing season limit corn yield more often than any other single factor. Both high rates of evaporation and erratic precipitation reduce soil water storage. In addition, surface runoff from sloping areas is a loss of potential soil moisture for use by corn. So we began this study to develop a suitable ways for crop production in the loess plateau of China in 1989.

MATERIALS AND METHODS

Soil tillage treatments

Five locations, Xinzhou, Taiyuan, Fenyang, Pinding, and Xixian were choosen according to land and climate conditions of Shanxi province. The treatments were A) No-tillage with whole cornstalks and half-mulching (NTHM). No-tillage after harvesting corn in fall, then whole cornstalks uniformly spread over the soil surface in the same direction with rows. Before planting maize in the following spring, move cornstalks into the area between rows and provides a trash-free zone for planting, in general, row area and covering stalks area were the same, that is half-mulching. At preemergence 300ml/ha 40% Atrazin was used to control annual weed, B) no-tillage with whole cornstalks and full-mulching (NTFM). All field operations previous to planting corn in the following year were the same as NTHM. But cornstalks having been moved must be recovered after emergence, made full-mulching, C) no-tillage without mulching (NT), and D) conventional tillage (CT).

All treatment were arranged in a randomized block design and replicated three times, plot areas were 66.7 m^2. Cornstalks rate was 11250 Kg/ha.

Surveying items

Soil moisture content was measured by direct sampling and oven-drying procedures in 10 cm increment to a depth of 100 cm or 200 cm. Soil temperatures were measured at 8:00, 14:00, 20:00 every day in the row in one replicate of each treatment at depths of 5, 10, 15, and 20 cm. Dry matter yield samples (weights of oven-dried tops) were taken at all locations every 15 days. The first corn samples were taken when the corn was appoximately 10 cm high (leaves extended) which include all growth above ground.

RESULTS AND DISCUSSION

Precipitation

During experimental period, precipitation varied within years as well as among years. In 1990, precipitation from April through August (crop growing period) in Xingzhou, Taiyuan, Pingding, Fenyang, and Xixian was 40, 37.9, 46.6, and 57%, respectively, of the 40-year average rainfall. In 1991, combining frequent rains in late April and May with long drought from June through August at all locations retarded milk development of the seed, finally corn grain yields were very lower. In 1992, drought period was from April through July, i.e. total rainfall amounts were only 0.3, 1.8, and 3.2 mm in April in Taiyuan, Fenyang, and Pingding, respectively.

Tillage system and maize grain yields

Corn grain yield was lower under NT than under CT. Results from 1990 through 1992 were: Corn yields under NT were lower 0.1%, 4.8% and 32.9% than CT, but under NTHM and NTFM were higher 34.3% than CT, respectively (Table 1).

Under normal precipitation, NTHM was very good, but under drought, NTFH was favorable to corn growth according to experimental results from 1990 through 1993.

Table 1. Corn grain yields under different tillage (Kg/ha).

Treatment	Year	Xinzhou	Fenyang	Pingding	Xixian	Taiyuan
NTHM	1990	6949.5	6802.5	7290.0	7831.5	5298.0
	1991	1003.5	1002.0	5238.0	2235.0	1357.5
	1992	7018.5	3397.5	5670.0	6930.0	4881.0
	Mean	4990.5	3734.0	6066.0	5665.5	3845.5
NTFM	1990	-	6822.5	7440.0	-	-
	1991	-	1468.5	5424.0	-	-
	1992	-	3604.5	6054.0	-	-
	Mean	-	3965.2	6306.0	-	-
NT	1990	-	-	-	-	4285.5
	1991	-	-	-	-	444.0
	1992	-	-	-	-	1720.5
	Mean	-	-	-	-	2150.0
CT	1990	6019.5	5986.5	6540.0	6499.5	4279.5
	1991	699.0	531.0	4719.0	2017.5	466.5
	1992	6030.0	2992.5	3480.0	5868.5	2565.0
	Mean	4249.5	3170.0	4913.0	4795.2	2437.0

Soil water content

NTHM and NTFM greatly affect first-stage evaperation, precipitation storage as soil water during fallow period was higher under NTHM and NTFM than CT (Table 2). The water content near the surface of mulched soil often was higher than that of bare soil, it was very useful for improving seedling establishent. After a full crop canopy is attained, there is little or no difference in soil water evaporation between CT and NTHM or NTFM (Table 3). Corn grown by the NTHM or NTFM transpired, on the average, more water than corn grown by the CT. Likewise, soil under the NTHM or NTFM lost less water to the atmosphere by evaporation than did soil under the CT, this improved efficiency of water use, water-use efficiencies were 17.4 and 15.2 $Kg \cdot mm^{-1} \cdot ha^{-1}$, respectively, under NTHM and CT.

Initial days after precipitation, evaporation was greatly controlled by mulch, the more mater can infiltrated deeply into the soil profile, and were protected. Precipitation 87.2 mm from June 2 through June 10 in 1991 in Taiyuan. Soil moisture at a depth of 200 cm was measured after 7 days. We found that depth of infiltrating water reached to 140 cm under NTHM or NTFM, but under CT only reached to 100 cm. Soil water content at 0~200 cm was higher 79 mm and 87 mm tban CT and NT.

Table 2. Soil water content during fallow period under NTHM and CT. (w/w, %, 1992).

Time	Depth (cm)	NTHM	CT
27 March	0-20	16.3	14.4
	20-50	12.8	12.7
	50-100	11.8	11.7
	100-120	10.2	9.0
	120-150	9.8	8.9
	150-200	11.2	11.1
	0-200	11.5	11.3
22 April	0-20	10.6	8.1
	20-50	11.5	11.0
	50-100	11.9	11.0
	0-100	11.4	10.4

Table 3. Soil water contents* at 0-50 cm depth (w/w, %, 1991).

	Stage of development			
Treatment	Seedling growth	Stem elongation	Anthesis	Ripening of the seed
NTHM	15.1	9.4	7.8	8.6
CT	12.7	6.8	6.7	8.7

* soil water contents were average values of 5 locations.

Soil Temperature

During the growing season, untilled soil were observed to be cooler than clean tilled soil. At a depth of 20 cm, the average difference in soil temperature ranged from 2.5 to 3.5 °C. The average soil temperatures were increased 1.1 °C at a depth of 20 cm under NTHM than NTFM, it is advantageous to promote early corn growth. The temperature defferences between mulched and bare soil gradually became small with increasing soil depth, i.e. lower 3.4 °C, 3.1 °C, 2.3 °C, and 2.3 °C at a depth of 5 cm, 10 cm, 15cm, and 20 cm, respectively.

Effects of no-tillage on corn growth

Growing point of the corn is under the soil surface before stem elongation, lower soil temperature under mulch will retard early season corn growth. Each growth and development stage was delayed 4, 6, 5 days for NTHM or NTFM compared to CT in Pingding, Taiyuan and Xinzhou, respectively. Corn growth and development were divided into two stages. Stage controlled by soil temperature. Before stem elongation, mulched corn at emergence were spindly with narrow-leaves in all years at 7 locations, less yield of dry matter at the first sampling was significant. Stage determined by soil water content. After stem elongation, as corn growth is under the shortage in water in semi-arid region, combining the more soil water under mulch with higher soil temperature is favourable to promote corn growth under the same air temperature condition, the significant later growth and yield increase were due to more favorable moisture conditions under mulch. Corn growth equations and accumulative dry matter equations for all treatments were in Table 4.

Table 4. Equations of corn growth and accumulative dry matter and characteristic values.

Treatment	Equation	Tmax	Vmax	T_1	T_2	Δt
CT	$Y=\frac{127.7}{1+EXP(2.51-0.05t)}$ $V=\frac{6.1xEXP(2.51-0.05t)}{(1+EXP(2.51-0.05t))^2}$	52.3	1.53	24.8	79.8	55
NTFM	$Y=\frac{150.7}{1+EXP(2.67-0.04t)}$ $V=\frac{6xEXP(2.67-0.04t)}{(1+EXP(2.67-0.04t))^2}$	61.1	1.78	30.9	91.3	60.4
NTHM	$Y=\frac{148.4}{1+EXP(2.59-0.04t)}$ $V=\frac{5.9xEXP(2.59-0.04t)}{(1+EXP(2.59-0.04t))^2}$	61.5	1.56	30.2	93.0	62.8
CT*	$Y=\frac{869.3}{1+EXP(6.5-0.068t)}$ $V=\frac{59.5xEXP(6.5-0.0685t)}{(1+EXP(6.5-0.0685t))^2}$	94.9	14.9	75.6	114.2	38.6
NTHM*	$Y=\frac{1169.3}{1+EXP(6.9-0.0693t)}$ $V=\frac{81xEXP(6.9-0.0693t)}{(1+EXP(6.9-0.0693t))^2}$	99.6	20.3	80.5	118.6	38.1

Tmax = days when growth (or accumulative dry matter) rate is maximum.
Vmax = the maximum growth (or accumulative dry matter) rate.
T_1 = heginning days when corn quickly grow.
T_2 = end days when corn quidkly grow.
Δt = corn fast growth (or accumulative dry matter) period.
CT* and NTHM* = equation of accumulative dry matter.

Lower soil temperature spindly seedling under NTHM and NTFM can mitigate a contradiction between water utilization and shortage in water in semi-arid region. The average amounts of soil water transpired through spindly seedlings to the atmosphere is smaller than strong sprouts, so more soil water is storaged. When drought happend in late season, it is favourable to mulched corn. So we think, lower soil temperature spindly seedling under NTHM and NTFM can strengthen drought-resistance of crop-soil-air system.

CONCLUSION

Compared to NT and CT,average corn grain yield under NTHM and NTFM increased by 34.3% during the 3-year period at 5 locations. Soil moisture contents were effectively increased. Soil temperature at 0-20 cm depth was lower throughout the growing season, but compared to NTFM, 1.1 °C soil temperature was incerased under NTHM, it is favourable to promote the early corn growth. Corn growth and development was divided into two stages, i.e. stage controlled by soil temperature, and stage determined by soil water content.
And we thank that, combining lower soil temperature with the early spindly corn seedlings could strengthen drought-resistance of crop-soil-air system in semi-arid region.

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THE EFFECT OF TRACTOR TRAFFIC ON COTTON PRODUCTION IN DARK CLAY SOIL

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ABSTRACT

The effect of tractor traffic on cotton production was investigated in a dark clay soil of Numan, Adamawa State of Nigeria. Thirteen treatments of machinery traffic consisting of three tractor contact pressures of 2.90 kg/cm^2, 2.25 kg/cm^2 and 1.34 kg/cm^2, four tractor passes of 5, 10, 15 and 20 and a control of zero traffic were employed using a randomized complete block design.

The soil and plant parameters measured include: soil dry bulk density, penetration resistance, appearance of first floral buds, tap root length and cotton yield. Results indicated that the penetration resistance, dry bulk denisity, days of appearance of first floral buds and cotton yield were adversely affected by increase in tractor passes irrespective of the tractor contact pressure. The adverse effect was mostly felt in plots treated with high contact pressures.

Growth models for the measured plant parameters were derived in terms of the product of contact pressure, the number of tractor passes and a number of measured soil parameters. The implications of the results in relation to dark clay soil management for cotton production were discused.

INTRODUCTION

The increasing level of mechanized crop production all over the world has generated a great concern because of the compaction which normally results when tractor wheels pass over soils. Several investigations from different parts of the world concerning the effect of soil compaction on crops have been reported in literature (Raghavan and Mckyes, 1978, Taylor and Burt, 1981, Ohu and Folorunso, 1989, Grath and Hakansson, 1992). Reports have shown that the magnitude of the effect of compaction is a function of soil type, soil moisture content, frequency of use of vehicular traffic and tractor tyre contact pressure. Compaction affects all stages of development of the crop. Dawkins (1983) reported a 50 % reduction in plant emergence and reduced root length due to top soil compaction caused by tractor traffic. Experiments conducted by Hehbleth Waite and Mcgowan (1980) revealed that compaction significantly decreased root, and sugar yield in sugar beet.

Similarly wheat yield was reported to be significantly affected (Maurya, 1985) by compaction from tillage operations in an irrigated Northern Nigeria soil.

From the available reports on the effect of soil compaction on crops, it appears that the severity of compaction is crop specific. The tolerance of crops to compaction varies from one crop to the other. For example, Ohu et al. (1991) reported that in a field experiment with a sandy loam soil, the highest yield of sorghum was obtained at 15 tractor passes while 5 passes of tractor traffic gave the highest yield of groundnut even though the treatments were imposed at the samle soil moisture contenct. It was also reported by the samle authors that silage corn yield decreased with increase in the number of tractor passes in the same field of sandy loam soil.

As it is the practice in many agricultural developing nations, the Federal Government of Nigeria is highly promoting the use of farm machineries into Nigerian agriculture. Before the oil boom periode in Nigeria, cotton used to be one of the cash crops of the country. This crop is grown mostly in heavy dark clay soils. Generally, very little work has been reported on the effect of soil compaction on cotton production. Researchers have always concentrated their studies on grains and legumes. Because the severity of compaction is soil and crop specific, it will be necessary to quantify its effect on an economically viable crop like cotton grown in a unique dark clay soil. The objective of this study was to assess the effect of tractor traffic intensity on the physical properties of a dark clay soil and on the yield of cotton.

MATERIALS AND METHODS

A four replication, randomized complete block experiment layout consisting of 4 treatments from 3 different tractor sizes and a control was set up in a dark clay soil field in Numan, Adamawa State of Nigeria. The soil of the study area is classified as Typic Pellusterts (Soil Survey Staff, 1975). The soil is made up of 10 % sand, 20 % silt and 70 % clay. The treatments consisted of a zero traffic and 5, 10, 15 and 20 passes of 3 tractors having rear axle loads of 131.32 KN/m^2, 220.50 KN/m^2 and 284.20 KN/m^2 respectively. The three tractors had the same rear tyre dimension of 16.9/14-30 where 429.26 mm is the section width, 355.60 mm is the section height and 762.00 mm is the rim diameter. The resultant ground contact pressure of the three tractors Steyr 768, 8073 and 8075 used for the experiment were: 1.34 Kg/cm^2, 2.25 Kg/cm^2 and 2.90 Kg/cm^2 respectively. The letters assigned to the tractors were: Steyr 768 = X; Steyr 8073 = Y and Steyr 8075 = Z. A schematic diagram of the experimental layout is shown in Fig. 1. The treatment combinations were imposed on the plots when the soil moisture content was 10 %, a moisture content lower than the critical value for the type of soil as recommended by Ohu et al. (1989) for that soil type.

The plots received a basal application of NPK compund fertilizer at the rate of 225 Kg/cm before seeding as recommended by AERLS (1983). Cotton seeds dresed with Fanasan D at 10 gm per 3 kg og seeds were sown per hole using a spacing of 45 cm within the row and 100 cm between rows. Each plot had nine rows and each row had 22 plant stands.

Soil bulk density, gravimetric moisture content and penetration resistance of the top 25 cm of the soil profile were measured immediately after traffic treatment. Consequent measurements of these parameters were taken 24 hours after every major rainfall in the area until harvesting was done 140 days after planting. Two weeks after emergence, thinning was done leaving the best of two seedlings per stand. Weeding was done manually at 3, 7 and 11 weeks after planting. The plant stands were top dressed with SSP (Single Super-phosphate) fertilizer when the plants were 3 weeks old. Spraying of the cotton to prevent insect infestation was done at 14, 15 and 16 weeks using Didigam in Knapsack sprayer as recommended by AERLS (1983).

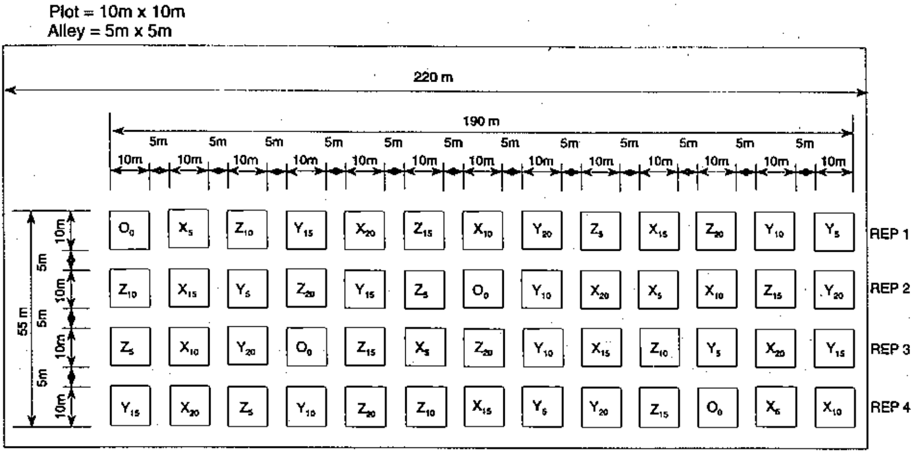

Fig. 1. Experimental layout showing the randomized complete block design of the plots (10 m x 10 m each). X, Y and Z are three different tractors of Steyr 768, 8073 and 8075. The subcrips represent the number of tractor passes of 1, 5, 10, 15 and 20.

Harvesting commenced 140 days after planting and alle lints collected per plot were weighed. All parameters measured were compared in terms of traffic treatments.

RESULTS AND DISCUSSIONS

Results of the gravimetric moisture content 24 hours after every major rainfall up to 25 cm's of the soil profile is shown in Table 1. Higher soil moisture content was observed in the plots that received high levels of traffic treatments. The higher the traffic intensity, the higher the moisture content. This might have been due to alteration in the pore size distribution of the soil induced by compaction in favour of water retaining micropores. Similar results were reported by Hassan and Broughton (1974). The mean comparison of the results showed significant difference ($P \leq 0.05$) between treatment means after traffic treatment. The moisture content of the soil can be represented in terms of traffic treatment in the form:

$$\theta p = 17.834 + 0.129\,(np) \qquad (1)$$

$$(n = 364,\ r^2 = 0.708)$$

where, θp = soil moisture content, np = product of the number of tractor passes and the contact pressure, n = number of observations, r^2 = coefficient of determination.

Table 1 Mean value of soil moistrue contents after every major rainfall (o/o).

Treatment	Periods					
	A1	A2	A3	A4	A5	A6
Control	10.05	11.11	12.21	15.91	18.20	20.51
05X	13.60	18.60	20.40	22.20	24.40	26.50
05Y	13.70	18.90	20.50	22.80	24.90	27.20
05Z	13.80	19.40	20.90	23.30	25.30	28.70
10X	14.90	14.90	21.40	23.60	25.90	28.70
10Y	15.20	19.70	21.80	23.90	26.80	29.60
10Z	15.80	20.20	22.20	24.50	27.20	30.00
15X	16.30	20.10	22.50	24.80	28.10	30.60
20X	17.30	20.70	21.10	26.20	29.90	31.80
20Y	17.60	21.20	24.40	26.60	30.20	32.70

Each value is a mean of 4 replicates. A1-A6 represent periods after every major rainfall. The effect of tractor traffic on soil bulk density and penetration resistance are shown in Table 2. From the table, it will be observed that bulk density and penetration resistance increased with increase in tractor traffic and also with increase in ground contact pressure. A similar trend of result had been reported by Ohu et al. (1993) in a lighter soil. Soil bulk density and penetration resistance were each statistically related to traffic treatment and moisture content in the form:

$$\rho = 2.672 - 0.734 \ln \theta + 0{,}475 \text{ pl } (np) \quad (2)$$
$(n = 312;\ r^2 = 0.37)$.

$$Pr = 2.227 - 0.718 \ln \theta + 0.945 \ln (np) \quad (3)$$
$(n = 312;\ r^2 = 0.64)$

where ρ = soil dry bulk density (Mg m^{-3}), Pr = penetration resistance (Mpa), θ = moisture content (Kg/kg), np = product of number of tractor passes and the contact pressure. The low coefficient of determination obtained for dry bulk density indicates that the variations in density of the soil cannot be accounted for by only moisture content and applied load. This result supports the school of thought by many researchers that the strength of the soil cannot be truly determined by the soil density. This clearly explains the better coefficient of, determination obtained for penetration resistance.

The results of the appearance of first floral buds, the tap root length and the dry cotten seed yield are shown in Table 3. It will be observed that the number of days after planting for the appearance of the first floral buds was significantly affected by traffic treatments. Statistical analysis of mean values of days in all the plots showed significant difference between the control and traffic treatments although there was no significant differences between the treatments. The number of days taken for the appearance of the first floral buds in all the treated plots was a little lower than the usual 38 days expected (Jordan, 1983) as obtained in the control.

Table 2. Mean values of soil bulk density (Mgm-3) and penetration resistance (Mpa) before and after traffic treatments.

Treatment	Before traffic		After traffic treatment											
			A1		A2		A3		A4		A5		A6	
	ρ	Pr	ρ	Pr	ρ	Pr	ρ	Pr	ρ	Pr	ρ	Pr	ρ	Pr
Control	1.20	1.08	1.21	1.10	1.11	1.11	1.11	1.01	1.01	1.05	1.01	1.05	1.01	1.04
05X	1.00	1.06	1.70	1.41	1.50	1.20	1.31	1.30	1.20	1.20	1.00	1.20	1.10	1.20
05Y	1.00	1.09	1.80	2.60	1.70	2.50	1.50	2.50	1.40	2.50	1.30	2.40	1.20	2.00
05Z	1.00	1.10	1.90	3.80	1.80	3.70	1.60	3.70	1.50	3.70	1.30	3.50	1.40	2.90
10X	1.00	1.11	2.00	1.80	1.90	1.80	1.75	1.70	1.60	1.70	1.50	1.60	1.40	1.50
10Y	1.10	1.07	2.10	2.90	1.90	2.82	1.80	2.80	1.70	2.80	1.60	2.62	1.40	1.50
10Z	1.10	1.08	2.20	4.00	2.00	3.90	2.00	3.80	1.80	3.80	1.60	3.70	1.50	3.30
15X	1.10	1.08	2.30	3.50	2.10	3.40	2.00	3.30	1.90	3.20	1.70	2.80	1.60	2.60
15Y	1.10	1.05	2.40	4.10	2.30	3.90	2.10	3.90	2.00	3.60	1.90	3.30	1.70	3.00
15Z	1.10	1.10	2.60	4.10	2.40	4.10	2.30	4.10	2.10	4.00	2.00	4.00	1.90	3.90
20X	1.10	1.08	2.60	3.20	2.50	3.20	2.40	3.10	2.20	3.10	2.10	3.10	1.90	3.00
20Y	1.10	1.11	2.80	4.30	2.60	4.30	2.50	4.20	2.30	4.10	2.30	3.90	2.00	3.60
20Z	1.20	1.02	3.50	5.40	3.40	5.10	3.30	5.00	3.10	5.10	3.10	4.80	2.90	4.40

Table 3. Means of days of appearance of first floral buds tap root length (cm's) and dry cooton yield ((Kg/ha).

Treatment	Days of appearence of first floral buds (days)	Tap root length (cm's)	Dry cotton seed yield (Kg/ha
Control	37.25	160.45	341.87
05X	34.75	156.23	346.36
05X	32.75	156.23	332.67
05Y	32.00	145.65	321.71
05Z	35.25	140.87	331.30
10X	34.50	138.00	328.70
10Y	33.00	130.78	320.40
10Z	32.00	120.24	321.90
15X	32.75	130.50	316.60
15Y	33.00	123.85	307.40
15Z	34.50	110.50	295.70
20X	33.00	125.75	286.80
20Y	34.50	115.25	277.40
20Z	36.25	105.34	

The tap root length was adversely affected by traffic treatments. There were significant differences in the tap root length of the control and the treated plots. The heavier the tractor used, the shorter the tap root length. Similarly for a particular tractor used, the higher the number of passes, the less the tap root length. The maximum tap root length recorded is within the range observed by Jordan (1983). The tap root length was related to the density and tractor traffic in the form:

$$TL = 154.884 + 0.242\ \rho - 0.953\ (np) \qquad (4)$$

$(n = 52;\ r^2 = 0.93)$

where TL = tap root length (cm), ρ = dry bulk density (Kg cm^{-3}), np = product of number of tractor passes and contact pressure (Kg cm^2).

From the mean values of dry cotton seed yield recorded, it was observed that tractor traffic affected the yield in a different pattern from that recorded for other parameters. Generally, the greater the tractor load, the lower the yield and the higher the number for tractor passes, the lower the yield recorded for the three tractor loads applied.

However, the least tractor weight produced the highest yield at 5 tractor passes, even more than the control. This observation indicates that some compation is needed for optimizing the yield of cotton. It will also be ohserved that for each of the tractor weights employed, the highest yield was recorded at 5 passes. The trend of result observed confirms the findings of Ohu et al. (1991) that though a certain amount of machinery traffic on the field can be beneficial to crop production, the severity of the traffic depends upon machine weight, tyre size and crop species. The cotton seed yield was related to soil moisture content and traffic treatment in the form:

$$Cy = 36.363 - 0.1024\ \theta - 0.098\ (np) \qquad (5)$$

$$(n = 52;\ r^2 = 0.809)$$

where Cy = dry cotton yield (kg/ha^{-1}), θ = soil moisture content (Kg/kg), np = product of number of passes and contact pressure, n = number of observations and r^2 = coefficient of determination.

CONCLUSION

The penetration resistance and dry bulk density of the vertisol were adversely affected by tractor traffic. The appearance of first floral buds was a little delayed than expected. Although the yield of cotton was affected by tractor traffic, a little amount of compaction would be needed for increased cotton production.

It can be concluded that even for fine-textured soils, a certain amount of machinery traffic on the field will be very beneficial to cotton production. As in the previous studies on maximizing crop production using farm machines, the need for careful choise of machine weight, tyre size and traffic timing for improved crop production was indicated from the results obtained.

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MINIMAL SOIL TILLAGE INFLUENCE ON THE ACTIVITY OF SOIL MICROORGANISMS

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ABSTRACT

The impact of soil tillage practices on soil microbiological and physical properties and on the crop yield was investigated in a stationary crop rotation trial over the period of 21 year. The trials were conducted with the view to minimize soil tillage in reclaimed light loamy soil.

INTRODUCTION

In order to minimize energy costs for soil tillage it is necessary to take into account crop yield, weed infestation level, soil physical and chemical properties as well as soil microbiogical processes. Soil tillage has a great effect on soil bulk density, distribution of plant roots and organic matter in the arable layer, air, water and temperature regime, therefore it has a significant influence on the action of soil microorganisms. References on this subject are rather scarse and contradictory. Most of the findings are based on soil and climatic condition and crops. Positive effect of minimum soil tillage on soil biological and other properties stipulating fertility, especially in the upper layer of the soil has been determined by many researchers in different countries and soils (1,2).However, some researchers point out negative effects of minimum soil tillage on some soil properties. Findings are available proving that soil tillage has no significant influence on soil biological processes. There are also findings confirming that surface tillage reduces the biological activity of soil and crop yield and increases the content of phytotoxic microflora.
Microbiological tests conducted over the period 1990 - 1992 in the soil conditions similar to this soil tillage trial have shown that conventional soil ploughing at 25 cm depth has created identically favourable conditions for microbe coenosis both in 0-15 and 15-30 cm soil layers, where even distribution of root mass and the highest organic matter content have been determined. Minimum soil tillage has resulted in the increase of microorganisms content in 0-15 cm soil layer and reduction in 15-30 cm layer as compared with conventional ploughing. The difference in soil bulk density and crop yield was very slight (3).

MATERIALS AND METHODS

The experiments were conducted over the period 1972 - 1992 (3 cycles of crop rotation) in reclaimed, soddy - gleyic neutral loomy soil which humus content in the arable layer was 2,2% by Tiurin.
Spring (pre - sowing) soil tillage practices at 8-10 cm depth - 1) cultivation 2) harrowing by tine harrow 3) rototilling were investigated on three autumn (primary) tillage backgrounds: I - shallow ploughing 10-12 cm; II - ploughing at 22-25 cm; III - rototilling at 15-18 cm depth.
The experiments were conducted in the 7 course crop rotation: winter wheat, potatoes, barley with underseeding, perennial grasses, potatoes, barley, veth - oat mixture. farmyard manure (60 t/ha to potatoes and veth - oat mixture) and mineral fertilizers were applied every year in compliance with the recommended rates to each crop (N60 P60 K60 - N90 P90 K120).
Soil samples to determine microbiological and physical properties were taken every year in spring at the beginning of plant growth period and in autumn after harvesting, from 0-10 and 10-20 cm soil layers.
The distribution of soil microorganisms was determined by dilution method on different agar media in fresh soil samples and the activity of enzymes - was determined in dry soil by the methods by Hofman and Vlasiuk modified of Chunderova.
Soil structure was determined by Savinov method, bulk density - by Katshinskis method (cylindres 100 cm^3 capacity), moisture content - by thermostat methot, total porosity was calculated by soil bulk density and soil particle density.

RESULTS AND DISCUSSION

Soil microbiological properties

Soil biological activity as is seen from the findings provided in table 1 hasn't gone down during the 3 crop rotations i.e. 21 year employing only shallow autumn ploughing at 10-12 cm depth or rotolling at 15-18 cm. Quite the contrary, the distribution of the investigated groups of microorganisms, except Azotobacter, and enzymic activity in both parts of arable layer, especially in the upper part (0-10 cm) was the lowest in the treatmens ploughed in autumn at 20-25 cm depth. Comparing shallow autumn ploughing at 0-10 cm depth with rototilling at 15-18 cm depth, more favourable conditions for the majority of the tested microorganisms were observed in case of shallow ploughing, however there was only slight difference in enzymic activity.
Spring soil tillage had less significant impact on biological efficiency than autumn tillage. The spreat of microorganisms was often stimulated more by rototilling and cultivation than harrowing, especially on the background of shallow autumn ploughing. However, soil tillage minimization, especially shallow autumn ploughing at 0-10 cm depth has stipulated a significant differentiation of microbe coenosis in the investigated parts of soil arable layer. In deeply ploughed in the autumn soil at 20-25 cm and especially in the treatment cultivated in spring the lower 10-20 cm layer contained only

Table 1. The impact of soil tillage practices on microbiological properties (1972- 1992)

Spring soil tillage at 8-10 cm depth treatments	Soil layer cm	Number of in 1g dry soil: bacteria millions, ammonifying	Number of in 1g dry soil: bacteria millions, assimilating mineral nitrogen	Number of in 1g dry soil: mould fungi thousands	Enzymic activity 1g of soil: urease mg NH_3 in 24 hours	Enzymic activity 1g of soil: invertase mg of gliucose in 48 hours
1st background - shallow ploughing at 10-12 cm in autumn						
Cultivation	0-10	9.32	11.82	48.1	0.86	60.8
	10-20	7.65	11.41	40.2	0.80	63.8
Harrowing	0-10	8.80	14.89	40.7	0.89	66.5
	10-20	6.82	9.94	37.6	0.84	63.5
Rototilling	0-10	9.64	14.00	43.1	0.89	66.9
	10-20	7.69	8.98	37.6	0.80	61.7
2nd background - ploughing at 22-25 cm in autumn						
Cultivation	0-10	7.62	9.32	41.3	0.80	62.3
	10-20	7.45	11.66	36.1	0.88	61.9
Harrowing	0-10	7.90	11.62	37.2	0.81	63.2
	10-20	6.85	9.87	34.4	0.80	60.2
Rototilling	0-10	7.44	11.36	38.4	0.86	60.9
	10-20	6.48	8.54	34.9	0.80	61.6
3rd background - rototilling at 15-18 cm in autumn						
Cultivation	0-10	8.62	9.82	39.3	0.85	66.9
	10-20	6.79	10.17	34.1	0.80	63.9
Harrowing	0-10	8.38	11.59	41.0	0.88	66.0
	10-20	6.29	11.13	35.5	0.86	63.0
Rototilling	0-10	7.70	12.36	35.1	0.90	65.1
	10-20	6.65	12.00	32.8	0.84	62.6
LSD_{05}	0-10	0.90	3.19	4.6	0.06	4.8
	10-20	1.10	3.35	3.9	0.07	3.7

Table 2. The impact of soil tillage practices on soil physical properties and crop yield (1972–1992)

Spring soil tillage at 8–10 cm treatments	Soil layer cm	Water-stable macroaggreg. >0,25	Water-stable macroaggreg. >1mm	Moisture %	Soil bulk density g/cm^3	Total porosity %	Yield thousands of feed units per hectare
1st background – shallow ploughing at 10–12 cm in autumn							
Cultivation	0–10	50.1	13.2	15.2	1.43	45.2	67.0
	10–20	54.7	14.4	14.5	1.48	43.2	
Harrowing	0–10	50.5	12.8	15.0	1.43	45.1	67.0
	10–20	55.5	15.4	14.0	1.53	41.5	
Rototilling	0–10	49.8	12.8	15.1	1.44	44.9	66.7
	10–20	55.9	15.5	14.3	1.50	42.1	
2nd background – ploughing at 22–25 cm in autumn							
Cultivation	0–10	51.6	10.3	15.2	1.40	46.4	68.9
	10–20	55.0	10.9	15.1	1.45	44.6	
Harrowing	0–10	50.8	10.3	15.1	1.38	47.0	68.4
	10–20	53.6	11.1	14.9	1.43	45.3	
Rototilling	0–10	50.6	9.9	15.3	1.42	45.8	67.8
	10–20	54.2	10.9	15.0	1.45	44.3	
3rd background – rototilling at 15–18 cm in autumn							
Cultivation	0–10	52.8	13.7	15.4	1.38	47.1	69.3
	10–20	57.8	16.3	14.4	1.49	43.1	
Harrowing	0–10	54.4	14.7	15.6	1.40	46.6	69.5
	10–20	58.6	17.0	14.4	1.48	43.2	
Rototilling	0–10	52.8	13.3	15.3	1.36	47.7	68.4
	10–20	55.7	15.5	14.3	1.50	42.4	
LSD_{05}	0–10	2.8	1.9	0.4	0.03	1.3	2.7
	10–20	2.2	2.8	0.5	0.05	1.7	

incosiderably less microorganisms than the upper layer and sometimes even exceeded it. This is evidently, related to favourable moisture regime, soil porosity and bulk density.
The intensity of organic matter mineralization according to the ratio of microorganims growing on mineral and organic media was the lowest in case of autumn rototilling, spring cultivation, especially in 0-10 cm layer, which conforms to humus accumulation in the soil of this treatment.

Soil physical properties
Minimization of soil tillage had no negative effect on physical soil properties (table 2). Only lower part of arable layer (10-20 cm) was more dense owing to shallow autumn ploughing and rototilling, irrespective of pre-sowing soil tillage practices. The upper part of soil was most friable on the background of autumn rototilling. The least soil friability difference between layers was observed on the background of conventional ploughing in all the three treatmens.
Soil moisture was also almost identical in all the treatments and backgrounds, however a bit higher was detected in the lower soil layer on the background of deep ploughing. The highest number of water stable macroaggregates >0,25 mm and coarse aggregates bigger than 1mm diametre troughout the whole arable layer was found on the rototiled background in all the treatmens. The lowest number of coarse aggregates (>1mm) was found on the background of deep ploughing, this fact is also confirmed by other researchers (Jurencak, 1978).
There was no significant yelds difference among the treatments, however a bit higher yield was obtained in case of autumn rototilling. Pre-sowing soil tillage has no significant influence on soil physical properties and crop yield.

CONCLUSIONS

Minimum soil tillage had no negative effect both on soil biological and physical properties and on the crop yield of the crop rotation.
It is feasible to minimize autumn soil tillage in reclaimed light loamy soil, and instead of ploughing at 20-25 cm depth to employ shallow ploughing at 10-12 cm or rototilling at 15-18 cm.

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TWO-STEP CULTIVATION SYSTEM FOR OPTIMIZATION OF PHYSICAL REGIME ON LOAMY-SAND SOD-PODZOLING SOILS

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ABSTRACT

Elaborated soil cultivation system includes minimum tillage before planting for seedbed preparation - no more that 10-12 cm (first step) and basic tillage after planting from 20-25 up to 30-35 cm (second step).

The field experiments with potato, maize and oats were carried out during 1986-1993 on loamy-sand sod-podzolic soil, which consists of 88 % sand and 12 % clay including 5 % silt. The average rainfall is 580 mm per year.

For seed germination and early growth of cereal crops, comparatively dense soil is better (1.48-1.50 Mg/m^3), but for plant growth comparatively loose (1.35-1.45 Mg/m^3) show a preference.

For the tested crops it is possible to optimise soil physical conditions as desirable for plants growth by changing the time of basic tillage from preplanting, as usual, to postplanting period.

Such a system creates optimal physical conditions of in-stable light sandy soils for start growth and for all period of growth after germination. It permits an increase in yield of tested crops by 10-15 %, in some condition up to 18-20 %, without any additional expence of materials, energy and time.

INTRODUCTION

During the last 30 years in the former Soviet Union a lot of work has been done to estimate an optimal soil density parameter on different soils for different crops. The standard method for these purposes include the creation, before planting at field conditions in microplot experiments or in pot greenhouse experiments, the different levels of investigated factor (the soil density in our case), growing up the exact crop and estimation of its optimal parameters on the basis of obtained yields. Sometimes it may be standard field experiments, where different soil physical conditions are created by different soil tillage methods and compaction by running gears of tractors, vehicles or any another technical sources.

This technology is conventional, but has some difficulties in its use, when a sandy soil and when crops, which have a comparatively long period between planting and shoots emergence, when the natural drift of initial values of density, especially at the low level part of the density scale, has a high probability.

In correspondence with afore mentioned consideration we had payed attention on the general principles in potato growing technologies with mechanical weed control, which are widely spread in the forest zone of Ukraine on the soil of light mechanical composition.

The time between planting and beginning of vegetation at the local conditions on average is 23-25 up to 30-35 days at very cold wet springs. In such circumstances the time when the optimal soil density parameters has to be created, must be estimated more exactly.

From one side plants requirements to soil density before planting and germination may be different. On the other hand, under influence of the natural and antropogenic factors, the optimal parameters, created before planting, may be considerably changed to the time the plants really use them under influence of the natural and antropogenic factors.

Taking into account the slow plant development before germination and the main importance at this time of the temperature factor in the local layer of the tubers placement, we supposed that before germination plants requirements to soil physical conditions are confined to the topsoil (10-12 cm) and spread on all arable layer only at the beginning of vegetation. It was the main precondition for the two-step technology method elaboration.

The first step of this system is seedbed preparation before planting to the depth which is required for tubers (or seed when another crop). The second step, in fact the basic tillage, is the cultivation to the full deepness of plow layer or more by non-mouldboard tools some days before or after germination.

MATERIALS AND METHODS

The investigation was carried out in Forest zone of Ukraine over 1986-1993 on loamy-sand sod-podzolic soil, which consists of 88 % sand, 12 % loam, including 5 % silt. Humus content is 0.8 %. Average rainfall is 580 mm per year. The tested crop was: potato, oats and maize.

The elementary plots for row crops was 140 m^2, for oats-100 m^2 in four replications. The previous crop for row crops was winter wheat, for oats-maize.

Stubble cultivation, when row crops, included two cultivations (8-12 cm) by heavy disk harrow with manuring 30 t/ha before second operation. The level of mineral fertilization for potato and maize 120 N, 80 P, 120 K for oats-60 NPK.

Experiments with potato were carried out on two elements on relief: on the flat parts of fields and in the depressions, which are usual for landscape and occupy near 25 % of the total area.

The experiments includes following variants: fall plowing 23-25 cm, spring plowing 23-25 cm, fall discing 10-12 cm, spring flat cut cultivation 23-25 cm, fall discing 10-12 sm + flat cut cultivation 23-25 cm after planting, before or in time of germination. Preplanting cultivation from 5-6 to 10-12 cm was general for all treatments.

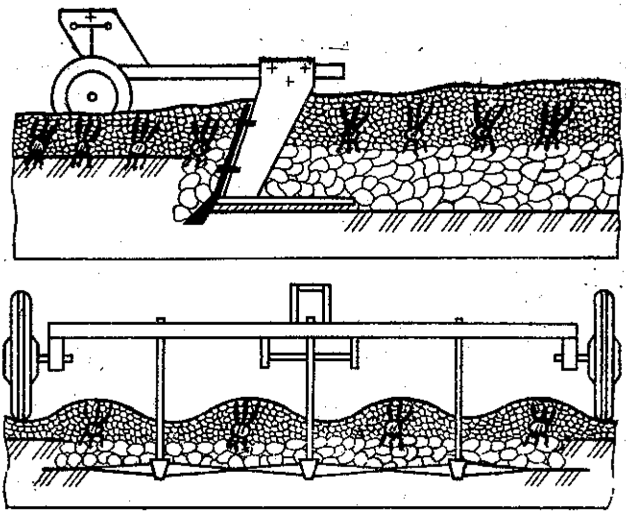
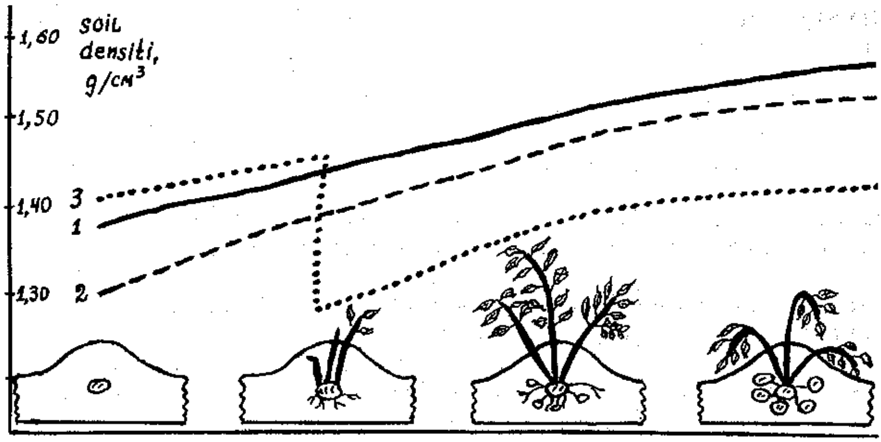


Fig. 1. The general scheme of two step technology.

RESULTS AND DISCUSSION

The main result of changing the time of basic tillage from preplanting to postplanting period, exactly before germination or in time of start growth of field crops, was soil density stabilization over all period of crops vegetation (fig. 2).



1 = fall plowing; 2 = spring plowing; 3 = two step technology

Fig. 2. Influence of time of basic tillage on the soil compaction process on potato field.

The use of the mentioned principle of two step technology permits to decrease the compaction influence of the main natural and antropogenic factors (Table 1) and create preconditions for activation of growing crops in biostabilization of soil in comparatively loose state for a long time. In condition of two step technology the processes of organic matter mineralization on light loamy-sand soil are artificially suppressed in preplanting period and their activation by deep basic tillage exactly in time of their products utilization by plants. So, in time of potato budding mineral nitrogen storage on two step technology plots was 12-22 kg/ha more than on spring plowed plots and 33-41 kg/ha than on fall plowed plots.

Table 1. The natural and antropogenic factors of soil compaction on potato field under influence of different time of basic tillage.

The time of basic tillage	Dates	The time between basic tillage and full germination		The number of mechanical operation in period			
		days	average precepitation mm	basic tillage planting	plant-germination	germination lifting	all operation after BasTill
Before planting (control)	25.04	32	75	2	2	4	8
Exactly after planting	25.04	32	75	-	2	4	6
After first pre-emergence interrow cultivation	04.05	21	56	-	1	4	5
After second pre-emergence inter-row cultivation	14.05	11	41	-	-	4	4
10 % germination	21.05	6	23	-	-	4	4
Full germination	26.05	0	0	-	-	3	3

The other important action of this type of technology is more uniform potato yield, on the acreage of field on it's flat parts micro and macrodepressions, because of sufficient water permeability as a result of the second step of technology.

The complete positive effect of two-step technology on the soil conditions of plant growth resulted in potato yield increase by 18 % comparatively to standard technology with the spring plowing.

Further experiments with maize and oats showed that the potato crop was not an exception and that the proposed principles may be general for other crops at the similar soil and climatic conditions (Table 2).

Table 2. Comparative effect of conventional and two-step treatments on the yield of some field crops on loamy-sand sod-podzolic soil (t/ha).

Basic tillage scheme			The yield, t/ha		
autumn	spring		Potato 1986-1988	Maize 1992-1993	Oats 1992-1993
	before planting	after planting			
Disking 10-12 cm			31.2		
Disking 10-12 Plowing 23-25 cm			32.0	4.17	3.81
Disking 10-12 cm	Plowing 23-25 cm		38.6	4.55	4.03
Disking 10-12 Flat and cut culti-vation 23-25			31.4	4.16	4.02
Disking 10-12 cm	Flat cult culti-vation 23-25 cm		35.9	4.90	4.14
Disking 10-12 cm		Flat cut culti-vation 23-25	45.4	5.27	4.43
LSD.95 (Mg/ha	n.a.	n.a.	3.1	0.34	0.31

CONCLUSION

On the basis of seven years of investigation with different crops some preliminary conclusions as to general principles of two step technology for loamy-sand sod-podzolic soils may be outlined:

1. The requirements by seeds and seedlings to physical conditions are limited to a narrow zone around the point of planting. For the case of growing plants this zone is extended to cover the whole root zone.

2. In time of seeds germination comparatively dense soil is best, but in time of growth-comparatively loose soil is preferable.

3. The changings of plants requirements to soil physical conditions occured in a short time of conversion from endospermal (or from tuber) to root nutrition.

4. On loamy-sand sod-podzolic soils, for some crops it is possible to change tbe soil physical conditions desirable for plants growth direction at the early growing period in correspondence to requirements of plants at the afore mentioned periods.

5. It is one of the possible ways to decrease the negative influence of soil compaction on the plant growth and increase the yield of some crops without additional expence of energy, materials and time.

EFFECT OF COMPACTING A LOESS SOIL ON ITS PHYSICAL PROPERTIES AND PLANT EMERGENCE

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ABSTRACT

The effect of different preplant tillage methods on soil physical properties as well as emergence and yields of spring barley was investigated. The changes in soil compactness brought about by different preplant tillage methods affected soil bulk density, moisture content, ODR and Eh and influenced performance of spring barley.

INTRODUCTION

As the soil is being worked the impact of the wheels of tractors and other agricultural machinery produces its deformation and unintentional excessive compaction. Among the principal causes of the deterioration of conditions for plant emergence and growth are: decrease in the amount of available water brought about by reduced soil porosity, deterioration in aeration conditions and rise in penetration resistance that restricts root growth (1, 2, 3). The aeration conditions are among the most important factors of plant development (4, 5).

MATERIALS AND METHODS

The experiment was run on a loess soil in the years 1987 - 1990. The design was a strip trial with four replications. Plot size was 6 by 15 m.

The experiment layout involved the following tillage treatments:
I - conventional tillage
II - soil worked using a double-wheeled tractor with an opener of wheel tracks penetrating to the depth of 20 cm
III - soil compacted by a single pass of tractor wheels - tracks running side by side
IV - soil compacted by three passes of tractor wheels - tracks running side by side

In order to measure soil electrochemical properties records of aeration conditions were taken at 0-20 cm depth using a multipurpose probe. The probe was equipped with a platinum and calomel electrodes.

The measurements of soil bulk density and moisture content were also taken from the arable layer during barley emergence using 100 cm^3 cylinders.

RESULTS AND DISCUSSION

In Table 1 are shown the data of the statistical analysis concerning the physical properties of the loess soil subject to different tillage treatments. The analysis of variance revealed that soil bulk density, oxygen diffusion rate (ODR) and redox potential (Eh) were significantly related to the method of preplant tillage.

Table 1 Effect of tillage treatment on the physical properties of the loess soil (values averaged over three years). Not significant: n.s.

Trait	Tillage treatments				LSD (.95)
	I	II	III	IV	
Density ($Mg \cdot m^{-3}$)	1.48	1.47	1.51	1.54	0.033
Gravimetric moisture v/v (%)	26.99	26.93	26.66	27.26	n.s.
ODR ($\mu g \cdot m^{-2} . s^{-1}$)	95.83	114.11	80.32	70.02	27.699
Eh (mV)	349.1	371.6	342.4	331.2	18.81

There was no significant effect of tillage treatment on soil moisture content.

The use of the double-wheeled tractor with a 20 cm track opener was beneficial to the soil properties under investigation. That treatment resulted in a decrease of soil bulk density and in a rise of ODR and Eh values.

Three passes of tractor wheels brought about further adverse changes in the properties studied and, consequently, an even more severe deterioration of plant growth conditions.

Table 2 shows the response of spring barley to the preplant tillage treatments. The analysis of variance proved a significant dependence of seeding depth and yields of spring barley upon the way in which the loess soil was tilled.

Table 2 Effect of preplant tillage treatments on the emergence and yields of spring barley grown on the loess soil. Not significant: n.s.

Trait	Tillage treatments				LSD (.95)
	I	II	III	IV	
Seeding depth (cm)	2.6	2.7	1.9	1.6	1.05
Plant number per 1m	35	40	37	33	NS
Grain yield ($t \cdot ha^{-1}$)	5.13	5.26	5.12	4.73	0.454
Straw yield ($t \cdot ha^{-1}$)	3.55	3.69	3.95	3.35	n.s.

The impact produced by three consecutive passes of tractor wheels during seedbed preparation had the most adverse effect on plant emergence and yields. As a result of that treatment, there was a 7.8% yield reduction on the control .

Preplant tillage involving the use of double-wheeled tractor with a track opener had the most favourable effect on seeding depth, number of plants after emergence and yields of spring barley.

CONCLUSION

The use of double-wheeled tractor with a 20 cm track opener in preplant working of the soil produces the best effects with regard to the improvement of soil conditions. This approach to preplant tillage secures improved crop yields and is recommended as effective in alleviating wheel track-related soil compaction.

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EFFECT OF SOIL COMPACTION AND METHOD OF SEEDING ON WHEAT ESTABLISHMENT AND YIELD IN VERTISOLS OF GEZIRA

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ABSTRACT

This research was carried for two seasons (1991/92 and 1992/93) and included two experiments: one on Gezira Research Station and the other on farmers fields in the Gezira Scheme. The soils in the two locations are heavy clay Vertisols and the environment is hot, dry and irrigated.
In the first experiment three methods of seeding and three compaction levels were tested. The design of the experiment was randomized complete blocks with four replications. The seeding methods included: seed drilling and tine covering, broadcasting and disc harrow covering, and broadcasting and tine covering. The compaction levels were zero, 1.25 and 1.55 kPa. Compaction was performed using a coil type harrow packer.

Results showed that compacting the soil after seeding at the tested levels did not affect yield significantly. However, in the on-farm experiemnt easiness of first watering in the compacted plots was reported by the farmers.

INTRODUCTION

The Gezira scheme is one of the largest irrigation projects under one management. With a total area of about 880 000 ha, wheat is cultivated in an area of about 220 000 ha. This contributes to about 70 % of the domestic supply of wheat in Sudan (Sudan Gezira Board, 1992)

Crop establishment is one of the important factors affecting wheat production in Gezira (Hassan and Faki, 1993). The seeding operation is performed using different types and makes of machines. Kepner et al. 1978 stated that a seed planter is required to perform the following: open the seed furrow to the proper depth, meter the seed, deposit the seed in the furrow in an acceptable pattern, and finally cover the soil and compact the seed to the proper degree for the type of crop involved. This gave the idea that by manipulating covering and compacting the soil after seeding, improvement in crop establishment could be achieved. Research done in the Central clay Plain indicted that positive results were obtained by compacting the soil after seeding for sorghum and sesame (Sim Sim Dryland farming Project, 1989).

The objectives of this research were to investigate the effect of compacting the soil after seeding for different seeding methods. The over all objective was to improve crop establishment and yield.

MATERIALS AND METHODS

This work was carried for two seasons (1991/92 and 1992/93) and included two experiments: one on the research station and the other was on farmers fields in the Gezira Scheme.

The first experiment was conducted at Gezira Research Station (GRS) Farm (14^0 24′ N). The soils at GRS are cracking heavy clay Vertisols. Details of the physical and chemical characteristics of the GRS soils is shown in table 1. The climate is semi-arid with mean annual rainfall of 400 mm, falling between June and September.

Table 1. Physical and chemical characteristics of Gezira soils

Depth cm	Clay	Silt	Sand	CEC meq/ 100 g	pH	EC mmohs / cm	organic carbon %	total N ppm
0	54.1	29	16.9	88	7.8	0.95	0.52	340
5	55.8	28.6	15.6	86	7.9	0.36	0.41	270
23	57.5	27.5	15.0	84	8.2	0.50	0.37	220
45	58.7	26.5	14.8	82	8.0	0.59	0.36	

Land preparation was done using two disc harrows and levelling. Wheat (Debeira cv) was sown on December 2nd, 1991 and on November 28 , 1992 at a seed rate of 143 kg/ha. Plots were 5 X 15 m. Fertilization (urea fertilizer at the rate of 2N (86 N kg/ha) and superphosphate at the rate of 1P (43 kg P_2O_5 kg/ha) was drilled before seeding. Irrigation was at intervals of two weeks. A total of seven irrigations was applied. Harvesting was on April.

Three methods of seeding and two harrow packing levels in addition to a control were arranged factorially to make nine treatments in a randomized complete block design with four replications.
Seeding methods included:

A. Seed drilling at 20 cm rows at a depth of 5 cm with a spring tine covering device.
B. Broadcasting and using a single row disc harrow as a covering device.
C. Broadcasting and using spring tines as a covering device.

Harrow packing was at three levels:

Zero: no harrow packing
low : harrow packing at the rate of 1250 kg/m^2
High: harrow packing at the rate of 1550 kg/m^2

Machines used in this experiment included ;

1.A Nordstein seed drill equipped with stubbed roller metering device, tine furrow openers and a spring tine covering attachment.

2. A Single row disc harrow: a Balmett, 9 discs, 50 cm diameter with an effective width of 2.0 meters.

3. A Blanchard Canadian made, coil type, trailed harrow packer.

The seeding methods treatments were performed as follows:

A. The seed drill treatment included using the deed drill with its tine furrow openers and its spring tine covering device.

B. The furrow openers and the tine covering device were removed from the seed drill; the machine was used as a broadcaster. Covering was done by the single row disc harrow. This treatment simulates the wide level disc.

C. The furrow openers were removed from the seed drill, and it was used as a broadcasting machine with the spring tine covering device.

As for the compaction, the high level was attained by adding extra weights.
Data collectd included: bulk density (wet), establishments data, yield and yield components.

The second experiment was conducted under farmers fields at the Gezira Pilot Farm, Taiba Block. In the first season (1991/92) a total area of 50 ha was used, while in the second season the area was 24 ha. Land preparation was done by ridging, split ridging, harrowing and levelling. Seeding was done using a seed drill at a seed rate of 143 kg/ha. Each farmer's holding was divided into two halves : one was compacted at a rate of 1250 kg/m^2 using the coil harrow packer while the other half was left as a control. A total of 24 and 14 replications were used in the first and second season respectively.

RESULTS AND DISCUSSION

Soil compaction is inherently neither good nor bad; the verdict is dependent on the intended use (Taylor, 1990).
Effects of treatments on bulk density are shown on figure 1.These bulk density values were measured at soil moisture content of 28%
No difference between the treatments in bulk density was observed.
Yield results of the first experiment are shown in table 1. Statistical analysis showed that compaction did not affect the yield significantlyin in both seasons. However, in the first year seeding method A had significantly low grain yield than the other two treatments.

FIGURE 1. EFFECT OF TREATMENT ON BULK DENSITY

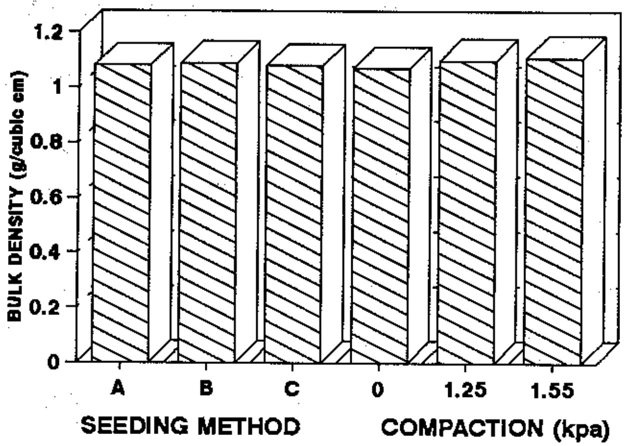

FIGURE 2. EFFECT OF COMPACTION ON ON-FARM WHEAT YIELD

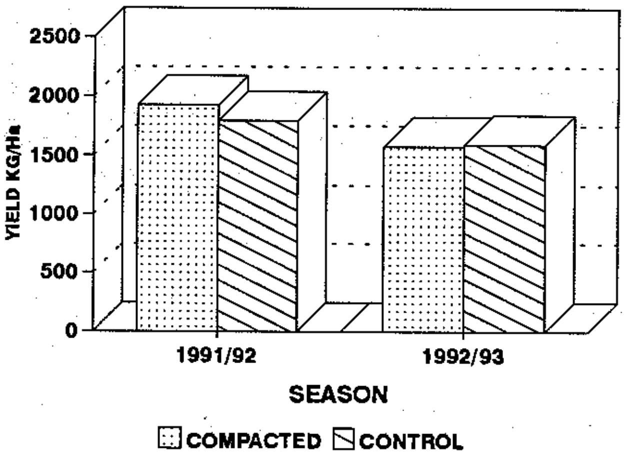

Table 2. Effect of Compaction and seeding method on wheat establishment and yield.

Treatment	Plant population plants/m_2		Yield kg/ha	
	1991/92	1992/93	1991/92	1992/93
Seeding Method				
A	188	290	2069	2489
B	218	295	2618	2582
C	208	281	2515	2397
Compaction (kg/m^2)				
zero	206	285	2411	2461
1250	201	287	2354	2482
1550	208	300	2438	2528
Mean	205	291	2401	2489
SE ±	14.7	67.3	108.9	22.2

In the on-farm trial farmers reported that compacted areas were easier to irrigate , specially the first irrigation which is a critical one. It took less time to irrigate the compacted areas. This is mainly because the harrow packer coil makes small furrows which facilitate the flow of water. However no diffrereces were observed in earliness or percent establishment of the crop. Yield data for the on-farm experiment are shown in figure 2. In the first season the compacted area outyielded the control by 7%. Mean yield in the compacted and control areas were 1924 and 1797 kg/ha respectively. In the second season no differences were observed between the two treatments. Mean yield in the comacted area was 1581 kg/ha, while the control area resulted in a yield of 1598 kg/ha.

CONCLUSIONS

1. No difference in yield was observed between the different seeding methods.
2. No interaction between seeding methods and compaction was observed.
3. For the compaction levels tested in this experiment no diffrenece in wheat yield could be found.

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SOIL BULK DENSITY PROFILES AFTER 10 YEARS OF DIFFERENT TILLAGE METHODS IN CENTRAL ITALY

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The first Author directed the research; the second author carried out the bulk density work, data analysis and discussion; the third author was responsible for the tillage and crop management during the 10 years of experiment.

ABSTRACT

Two field experiments were conducted in two locations for 10 years uninterruptedly to evaluate the effect of different tillage methods (conventional deep ploughing, reduced depth ploughing, two-layer tillage, minimum tillage) on two-course rotations (wheat-maize, wheat-sugar beet). At the end of the 10-year period soil bulk density profiles were examined.

INTRODUCTION

In Italian agriculture the conventional primary tillage is deep ploughing (0.4–0.5 m) with a mouldboard plough.
This causes some disadvantages such as deep soil layer inversion, large clod formation and organic matter dilution.

In the early 80's interest arose in the use of reduced tillage methods to reduce fuel consumption and avoid these disadvantages.
Hence it was necessary to verify whether these new tllage methods were suited to local soil types, climatic conditions and crops.

In 1981 experiments were initiated in Central Italy (Perugia) on a large farm scale and on experimental plots. The latter were used to reduce soil variability and improve the precision of comparing the long term effects on soil properties.

In this paper, attention is devoted to the soil bulk density, by examining soil profiles of plots after 10 years of using different primary tillage methods.

MATERIALS AND METHODS

Trials started in 1981 and were conducted uninterruptedly for a decade in two locations: Papiano, in the Tiber Plain, on a wheat-(irrigated) maize rotation and S.Apollinare, in a hilly site, on a wheat-sugar beet rotation. Both crops of each rotation were present every year.

The soil at Papiano is a clay silty loam (Fluventic Eutrochrept) and that at S.Apollinare is a clay (Typic Calciustert).

Soil tillage treatments

The different tillage practices used were:

A. Deep ploughing (conventional): 0.5 m depth for summer crops, 0.4 m for wheat.

B. Shallow ploughing: 0.3 m for summer crops, 0.2 m for wheat.

C. Two layer tillage (0.5 m subsoiling followed by shallow ploughing, 0.2 m) for summer crops, alternate with minimum tillage (disk harrowing, 0.10–0.15 m) for wheat.

D. Minimum tillage (disk harrowing) for both crops.

Each tillage method was applied according to a randomized design with four replications.

Crops were managed following conventional crop management practices, aimed at a good nutrient status and chemical weed control.

Yield data (not presented in this paper because of space) of each crop/location were submitted to a polyennial ANOVA.

In 1993, 10 years after the beginning of the experiments, observations were initiated on several soil physical and chemical characteristics. In the present paper bulk density profiles are presented and discussed.

Soil sampling

In each of the 16 plots of the S.Apollinare hill trial (4 treatments x 4 replications; last crop: sugar beet harvested in 1992) 1 meter deep trenches were made. On one side of the trench 7 layers were sampled, 100 mm thick, from the surface to 0.7 m.

Undisturbed soil samples were taken with steel cylinders (100 mm high and 85 mm in diameter) horizontally pressed into one side of the trench using an hydraulic jack.
Three soil cores were taken in each layer. The soil cores were dried in an oven and the dry weight was used to calculate the bulk density (or mass volume) in t m^{-3}.

In the Papiano plain trial a similar procedure was followed, but only on two of the four replications.

Bulk density data were analyzed to calculate mean and standard error (Figures 1 and 2).

RESULTS AND DISCUSSION

Figures 1 and 2 show the average bulk density along the soil profiles and the standard error bars of each mean.

The standard errors tend to be greater in the upper layers and/or in the plough layer, probably as a consequence of clod formation which increases heterogeneity of soil density. Standard errors are smaller in the less disturbed or undisturbed layers.
It seems advisable to improve sampling accuracy by increasing the number of core taken.

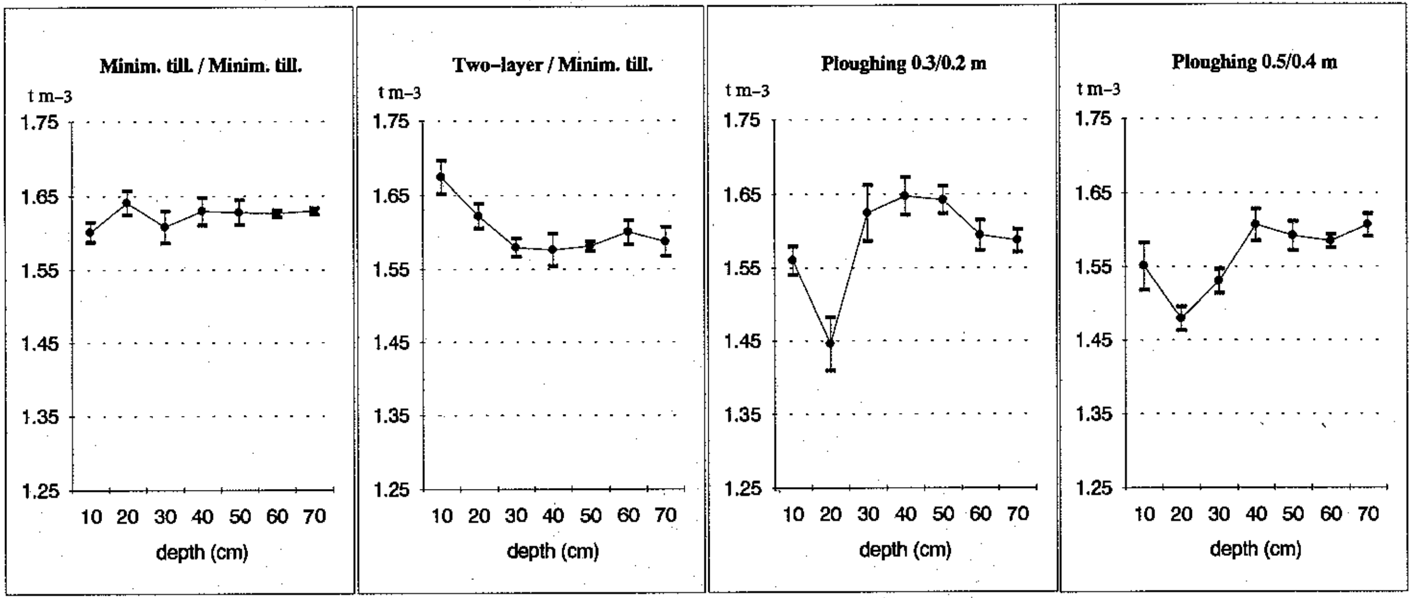

FIGURE 1 – Soil bulk density profiles (t m^{-3} ± standard errors) registered at Papiano (plain site, clay–silty–loam soil) after 10 years of different tillage methods.

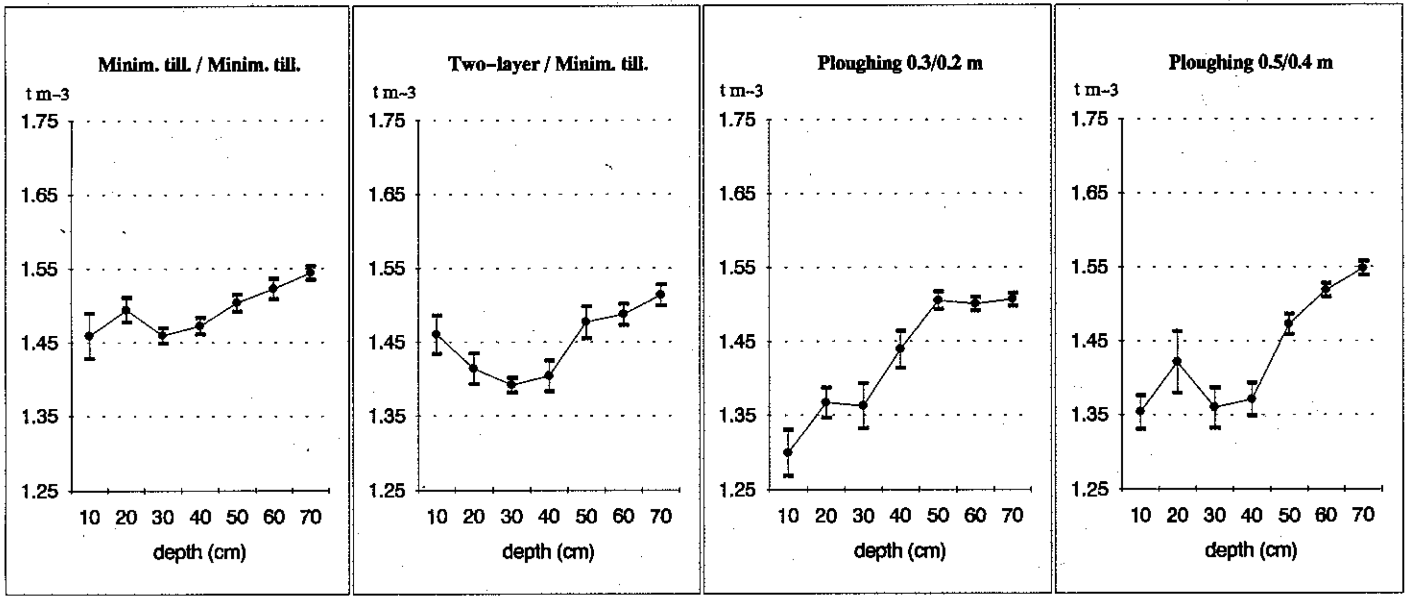

FIGURE 2 – Soil bulk density profiles ($t\ m^{-3}$ ± standard errors) registered at S.Apollinare (hilly site, clay soil) after 10 years of different tillage methods.

The two soil types (Inceptisol and Vertisol) have very different in their bulk densities. The Papiano soil, with less clay, has a "ceiling" density close to 1.65 t m^{-3}, while that of S.Apollinare has 1.55 t m^{-3} as maximum bulk density value.

The Papiano tendes to surface compacting, due to a less stable structure, while the upper layers of the S.Apollinare soil have a fairly low bulk density, due to the excellent reactivity of this soil to wetting and drying cycles and the consequent shrinking and swelling phenomena.

Effect of tillage methods

Soils under continuous minimum tillage have the highest and most uniform bulk density along the profile in both experiments, but in the Vertisol (S.Apollinare) a progressive and regular increase in bulk density in the deeper layers is observable. This could be due to the very high tendency of this soil to form large and deep cracks during summer shrinking.

Ploughing produced the greatest reduction in bulk density in the layers affected by the tillage tools.

Two layer tillage, alternate to minimum tillage, produced a bulk density status that is intermediate between minimum tillage and deep ploughing. The reduction in bulk density produced by subsoiling is less appreciable in the Inceptisol (Papiano) than in the Vertisol, probably because of the higher structure stability of the latter.

Crop Response

Results of polyennial ANOVA of yield data (not presented) show that deep ploughing did not have any favourable effect in comparison with shallow ploughing and two–layer tillage alternate to minimum tillage.

Only in the wheat–sugar beet rotation, continuous minimum tillage produced slight but significant yield reductions with respect to the other tillage methods. However it seems to be hazardous to attribute this effect directly and/or exclusively to the physical soil conditions, by considering that other agronomic factors could be involved.

CONCLUSION

After 10 years of application of different tillage methods, soil bulk density has been affected, the lowest values being produced by ploughing, the highest by continuous minimum tillage.

Nevertheless, wheat and maize (Papiano) yielded equally well, demonstrating that even at its highest values, bulk density (and the related soil porosity) is not a limiting factor for the growth of crops in that soil type.

In the S.Apollinare soil, continuous minimum tillage had some negative effect on yield (mainly in sugar beet).

In any case, deep ploughing never demonstrated any advantage over the other reduced tillage methods.

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Effects of repeated deep ripping of a Surface Waterlogged Luvisol

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Introduction

Deep ripping of compact subsoils, mainly of pedogenic origin, is quite often used nowadays as a technique to improve such soils in Germany (Schulte-Karing, 1970; Werner a. Unger, 1978), the U.S.A. (Wildman, no date), Russia (Zaidelman, 1985) and many other countries. In Romania, extensive field research was done on effects of deep ripping under various soil conditions. About 20 percent of the cropland of this country has been found to require deep ripping (Canarache, 1985), with yield increases of 10-15 percent (Nicolae, 1969; Boeriu et al., 1969; Stanga et al., 1975). Deep ripping is usually performed in this country at a depth of 50-70 cm and with a 100-140 cm distance between rippers, repeating this operation every 4-6 years (Colibas a.o., 1989).

Possible cummulative effects in a long term, whether positive or negative, resulting from repeated deep ripping of the same soil could be of interest. With positive effects, reducing the frequency of ripping could be possible, while with negative effects, ways to prevent unfavourable changes in soil properties should be found. Current research on plots ripped at 4-6 years intervals as in Romania, or at longer intervals as in other countries, could give an answer about such long term effects only at a later stage, possible too late to have a practical significance.

To get more rapidly some information on changes in soil properties due to repeated deep ripping and on crop response, a somewhat artificial field experiment was organized, and its results will be partially presented in this paper.

Material and methods

The field experiment was organized on the Sanmartin-Oradea site in the autumn of 1977, when the first deep ripping was performed. It is continuing from that year onwards.

The soil at Sanmartin-Oradea is a pseudogleyed Albic Luvisol (approximate FAO equivalent: stagnic Podsoluvisol). Within the experiment field two somewhat different varieties of this soil could be separated, located on two microrelief forms with a difference in relative altitude of no more than several decimeters but large enough to induce

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significant changes in the soil water regime. The first soil, located on the upper terrace, has moderate pseudogleyed features, while the second one, located on the lower terrace, has severe pseudogleyed features.

The eluvial horizon reaches ca 50 cm in the first case, and only ca 30 cm in the second one. Particle-size composition is that of a loam in the eluvial horizon (23-26 percent clay), and of a clay-loam in the clay-illuvial horizon (42 percent clay in the moderately pseudogleyed soil, and 45 percent clay in the severely pseudogleyed one). Saturated hydraulic conductivity is very low in the clay-illuvial horizon (2-3 mm/h in the moderately pseudogleyed soil and 0.4-0.8 mm/h in the severely psuedogeleyed one). The humus content is low (2.3 percent in the topsoil of the first soil and 1.8 percent in that of the second soil), and both soils are acid (pH in the topsoil 5.5-6.0).

Average climatic conditions at Sanmartin-Oradea are characterized by an yearly average temperature of 10°5 Celsius degrees, a frost-free season of ca.180 days, yearly precipitations of 635 mm, and yearly potential evapotranspiration of 689 mm. During the duration of the experiment weather conditions varied a lot around these averages figures.

The experimental design, which was not a very conventional one, consisted of six paralel strips of land, of which the two outer ones were not ripped (control plots), and the four inner ones were ripped each according to a specific frequency. The length of each of the six strips was separated into eight plots, four for each of the two soils, which were harvested separately and used as replications.

The treatments used, besides the unripped control, were with the following frequencies of ripping: 8 years (less frequently than usually in practice), 4 years (frequency generally used in practice), 2 years, and 1 year (more frequently than in present-day practice). According to these frequencies, deep ripping was performed on the experimental plots during the 1977-1993 period two times, four times, eight times, and fourteen times, respectively. Deep ripping was performed late autumn, after harvesting of maize, with a depth of 70-75 cm, and a distance between rippers of 100 cm. Special care was devoted to keeping the same ripper tracks all over the duration of the experiment.

A two-year rotation of winter wheat and grain maize, rotation which is widely used in this country, was used (with a short intercalation of oats and clover in 1988-1989) in the experimental field. The net profit for this period, taking into account prices at the September 1993 level, and the net energy output were calculated.

Soil samples and field determination of soil properties were done twice: in 1982 (results partially published, Canarache et al., 1985), and in 1990-1991 (results presented in this paper).

The volume of soil loosened by tillage and ripping was measured on soil profiles opened in the field across the direction on which the ripper was moving. Aggregate-size distributions was determined in the field, by dry sieving, and it involved the entire volume of loosened soil.

Soil sampling for laboratory determinations, as well as penetration measurements in the field, were originally done at different distances from the ripper tracks, and for different soil layers. In this paper only average data for the entire soil volume loosened by ripping are presented.

Bulk density and saturated hydraulic conductivity were determined on 100 cm^3 soil cores. Water-stable aggregates and dispersion were determined according to Hénin-Féodoroff. All determinations and sampling were done in April 1991. Soil moisture content and resistance to penetration were determined twice, in spring before seeding (April 1991) and in autumn after harvest (October 1990) as to get information for two extreme different soil water-storage conditions.

Results and discussion

A summary of the results concerning the soil properties determined in 1990-1991, as well as of the crop response (average data for the 1977-1993 period) is presented in Table 1. All data represent average figures for the two soils, the most striking differences between them being only discussed in the text.

With a ploughing depth of ca.20 cm., the volume of soil loosened in the control plot was not too much different from 2,000 m^3/ha. In the deep ripped plots, this volume varied between 3,300 m^3/ha and 3,700 m^3/ha, which represent 41-46 percent of the volume of the soil in the 80 cm layer taken into account. The volume of loosened soil showed a significant increase with increased frequencies of deep ripping, which is to be related to small, non avoidable, changes in ripper tracks.

There were quite significant changes in the aggregate-size distribution of the soil in the loosened layer. The aggregate mean weighted diameter decreased from 52 mm in the control plot to 38-40 mm in the ripped plots, with no significant differences between the various ripping frequencies. Differences in the mean weighted diameter were mainly due to a significant decrease in the content of clods >80 mm in diameter, from 29 percent in the non-ripped soil to 13-21 percent in the various ripping treatments. The mean weighted diameter, as well as the percent of clods, were much higher in the non-ripped treatment of the severely pseudogleyed soil.

Although determined only once, under a given soil moisture content, and pending on future data to be obtained at different times and under different soil moisture conditions, these results show an important fragmentation of the compact clay-illuvial horizon as a result of ripping, this fragmentation not being affected by more or less frequent repetead ripping.

Changes in bulk density of the soil layer most affected by ripping were not very important, and statistically not significant. This might be due to the relatively small size of the cores used, but it could also show a somewhat quick recompaction of the loosened soil. More obvious were the changes in the saturated hydraulic conductivity: from 3.6 mm/h in the control plot to 6-9 mm/h in the ripped plots, with a gradual increase as ripping frequency increased. It results that either this index is more adequate than bulk density, or the effects of deep ripping and of increased frequency of deep ripping are more intense on soil permeability than on bulk density .

Table 1

Summary of repeated ripping effects on soil properties and on crop yields (Sanmartin-Oradea, 1977-1993)

Index	Treatments					LSD
	None	8 years	4 years	2 years	yearly	
Vol.of loosened soil (m^3/ha)	2075	3296	3411	3562	3707	365*
MWD aggr.(mm)	51.7	40.2	40.3	37.5	40.9	1.9*
Bulk dens.(g/cm^3)	1.54	1.51	1.51	1.52	1.49	0.01
Sat.hyd.cond.(mm/)	3.6	6.0	6.9	8.5	9.2	0.17**
Wat.st.aggr.(%)	19.4	20.6	15.3	13.5	17.4	5.2*
Disp.ratio	5.9	6.3	6.0	6.3	5.9	1.5
Moist.cont.(% w/w)						
April 1991	17.7	20.2	20.1	20.4	21.7	2.1**
October 1990	14.7	14.2	13.9	14.9	15.5	1.7
Res.penetr.(MPa)						
April 1991	2.4	2.1	1.6	1.8	1.6	0.3**
October 1990	5.0	5.1	4.5	4.7	4.7	0.4**
Wheat yield (q/ha)	35.1	37.4	38.9	39.2	39.1	1.0*
Maize yield (q/ha)	39.2	43.3	45.8	48.5	50.3	2.2**
Net profit (th.lei/ha.year)	228	265	285	295	286	11**
Net energy output (th.KWh/ha.year)	31.5	35.1	36.8	38.1	38.7	1.4**

LSD for saturated hydraulic conductivity is given as log (mm/h)

Quite interesting are the data on soil moisture content. In spring, when there usually is a maximum water-storage, the moisture content of the ripped plots showed a significant increase of 2-3 percent over that of the non-ripped one. This effect was more pronounced on the severely pseudogleyed soil. In autumn, under conditions of minimum water-storage, the average data for the two soils did not show significant differences in moisture content, but when separate data were examined there was a significant decrease of 3-4 percent in the ripped plots in the moderately psuedogleyed soil. These data show an increase in the soil water-storage capacity as a consequence of ripping and, at least for the moderately pseudogleyed soil, an increase in water uptake by crops. The improved water regime of the soil as a consequence of deep ripping has been demonstrated earlier (Canarache et al., 1985) as one of the main causes for better crop development on ripped soils.

There was a significant decrease in resistance to penetration in the deep ripped plots (from 2.4 MPa to 1.6 MPa in spring, and from 5.0 MPa to 4.5 MPa in autumn), and at least some decrease due to more frequent deep ripping. These changes are in part direct consequences of changes of soil strength due to ripping, but also indirect consequences of changes induced by ripping in the soil moisture regime. The importance of such changes for root development is obvious in soils with rather high strength, as most of the soils requiring deep ripping are.

Examining yield data, as well as profit and energy otuput, several facts are to be mentioned. The positive effects of deep ripping on yields of both winter wheat and grain maize were of 10-20 percent, which is about the same range of magnitude as it was found in many previous experiments on similar soils throughout the country. The increase in yield was greater for grain maize than for winter wheat, and with both crops it was greater for the moderately pseudogleyed soil. Increased yields were accompanied by increases up to 10 percent in the net profit, and of more than 20 percent in the net energy output. Within the various ripping treatments, yields of grain maize showed a gradual increase all-over the various increases in ripping frequency. Increases in yields of winter wheat and in net energy output were not noticed with ripping frequencies over once every four years. Net profits showed even a trend of decrease when the ripping frequency was once every year.

Conclusions

Concerning the effect of a large number of repeated rippings, which was the specific objective of this experiment, it was shown that increasing the frequency of ripping did not induce neither negative nor positive soil or crop major changes. Although the technique of this experiment was not exactly reproducing the possible effects of a large number of repeated rippings performed with normal frequencies, and it is difficult to imagine such a technique, these results are in favour of not modifying the usual interval between successive rippings as used at present in this country.

Some new for this country and promising data were obtained in this experiment concerning the aggregate-size distribution of the soil layer loosened by deep ripping. Not without importance is the fact that earlier results on deep ripping effects under various soil and/or soil-water regime conditions, as well as on causes of deep ripping positive effects affecting crop yields and economic and energy outputs, were confirmed.

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EFFECT OF TILLAGE AND CROP ROTATION ON SOME CHEMICAL SOIL PROPERTIES OF A SHALLOW, SANDY LOAM SOIL.

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ABSTRACT

The distribution of organic matter (OM), plant nutrients and pH in the soil profile were examined after 17 years of conventional mouldboard ploughing (MDT), tine tillage (TT) and no-tillage (NT) in experiments where wheat was grown either continuously (CW) or in rotation with barrel medics (*Medicago trancatula*) as a legume pasture (PW). The experiments were conducted at Langgewens Research Farm in the southwestern coastal area of the Republic of South Africa where wheat is grown under a mediterranean climate on shallow (250-300 mm), stony, sandy loam soil. Tillage systems caused significant changes in the distribution of soil chemical properties. Although most chemical soil properties were higher with NT and TT when compared to MDT, the latter resulted in a more even distribution of properties in the 0-250 mm soil profile. With NT organic matter (OM), total N, P, K and pH were higher in the 0-50 mm, but lower in the 150-250 mm soil layers than with TT and MDT. This gradient was more pronounced where wheat was grown continuously for 17 years and may be the reason for the decline in grain yield experienced with long-term NT in this cropping system.

INTRODUCTION

Sustainable agricultural systems must maintain soil fertility and crop productivity (Lal and Pierce, 1991). Soils of the Swartland wheat-producing area in the Republic of South Africa are very shallow, stony and low in OM (Sim, 1958). Conventional mouldboard and disc ploughing, which encourage the decomposition of OM (Thomas, 1986) and soil erosion (Mannering, 1979; Packer and Hamilton, 1993), resulted in the degradation of the weakly structured A horison of the soils in the Swartland (Agenbag and Maree, 1989). Several researchers showed that minimum and no-tillage can increase soil carbon (Blevins, Thomas, Smith, Frye and Cornelius, 1983) and decrease erosion (Mannering, 1979) and soil crusting (Hamblin, 1984). These changes in soil properties are however mainly limited to the surface layers of the soil profile (Carter, 1991; Robbins and Voss, 1991; Unger, 1991; Gregorich, Reynolds, Culley, McGovern and Curnoe, 1993; Hermawan and Cameron, 1993), which arise some concern about the effect on crop growth and sustainability of

these tillage systems (Robbins and Voss, 1991; Unger, 1991).
In the Swartland, yields obtained with no-tillage increased in comparison with mouldboard ploughing during the 8th to 12th year of continuous wheat production (Agenbag and Maree, 1991). This was partly due to a higher nitrogen content in the 0-100 mm soil profile of the no-till soil. The relative high yields with no-tillage were maintained for several years but started to decrease after 15 years of continuous wheat production (unpublished data). As this tendency was not observed where wheat was grown in rotation with legume pastures we decided to examine the distribution of OM, various plant nutrients, and pH in the soil of the continuous wheat and pasture-wheat experiments at Langgewens.

MATERIALS AND METHODS

The tillage studies were conducted at Langgewens Research Farm about 70 km north of Cape Town in the southwestern coastal wheat-producing area of the Republic of South Africa and started in 1975. The soil at this site is a shallow (250-300 mm), stony, sandy loam on saprolite grading into fragmented shale and phyllite. The climate can be describes as mediterranean and nearly 75% of the mean annual rainfall of 412 ± 31.7 mm fell between autumn and spring.
The tillage treatments employed three systems using farm-scale equipment: (1) mouldboard ploughing (200 mm) followed by a disc-cultivation (MDT); (2) chisel plough (150 mm) followed by a field cultivator (TT); (3) no-tillage with a triple-disc drill after the weeds were sprayed with a non-selective herbicide. In the continuous wheat (CW) experiment the stubble of the previous crop was burnt before seeding. In the pasture-wheat (PW) experiment, wheat followed an initial period of 4 years pasture, the crops being rotated annually thereafter till 1985. Since 1986 two years of pasture were followed by two successive wheat crops.
No potassium fertilizer and only 12 kg of phosphorus were applied per hectare for each wheat crop. Wheat crops grown on pastures received 30 kg N per hectare, but fertilizer rates for CW steadily increased from 55 kg N ha^{-1} in 1975 to 120 kg N ha^{-1} in recent years. Lime was applied at a rate of 1000 kg per hectare to both experiments in 1980. In 1985 this application was repeated for the CW experiment only. Details of other produotion techniques were described earlier (Agenbag and Maree, 1989).
In 1991 soil samples were obtained before seedbed preparation started at depths of 0-50, 50-150 and 150-250 mm in both experiments. The seven sub-samples taken per plot were thoroughly mixed, dried and ground to pass through a screen with 2-mm openings before analysed for OM (Walkley-Black); total N (Kjeldahl); and P and K (citric-acid extration and determined by atomic absorption). The pH of the soil was determined on a soil:KCl suspension.
All treatments were replicated four times and every replication

was the average of two determinations. All data were subjected to analyses of variance and Tukey's LSD test was used to compare treatments at the 5% level.

RESULTS AND DISCUSSION

Results of organic matter (OM), total N, P, K and pH (KCl) determinations are given in Table 1. Tillage systems caused significant changes in the distribution of soil chemical properties. Differences in OM, P, total N and pH may be related to differences in placement and incorporation of fertilizers and crop residues as also shown by Carter and Rennie (1982).

In the mouldboard-ploughed soil (MDT) levels of all chemical properties were, with the exception of total N with CW, lower than with TT and NT, but did not differ significantly with soil depth. This confirmed earlier results (Blevins *et al.*, 1983; Carter, 1991) and illustrated the thorough mixing of the soil with mouldboard and disc ploughing. The only exception was K which had lower levels in the 150-250 mm compared to the 0-50 mm soil profile. Surprisingly, levels of total N did not differ much between the CW and PW cropping system with MDT. This is most probably due to high rates of mineralization with conventional mouldboard and disc tillage (Thomas, 1986) and the deeper placement of medic seed which resulted in lower populations of medicplants, less vigorous pasture growth (visual observation) and reduced nitrogen fixation.

With TT soil depth had no effect on soil pH and P, but the levels of K, total N and OM decreased with soil depth in both the CW and PW cropping systems.

In the CW cropping system NT resulted in significant vertical stratification of all chemical soil properties. Although P levels dropped from 95.3 in the surface to 65.3 mg kg^{-1} in the 150-250 mm soil layer, and K from 185.3 to 94.8 mg kg^{-1}, all values were above minimum for optimum crop growth (Tisdale, Nelson, Beaton and Havlin, 1993). It was therefore unlikely to have any effect on yield. The gradient in K which was found with soil depth for all treatments was somewhat surprising as no K fertilizer was applied throughout the duration of both experiments. This may be the result of increased release from the potasium-rich parental rock in the soil layers subjected to tillage, but still did not explain the significant higher levels found with NT in the 0-50 mm. However, similar results were obtained by Unger (1991) in experiments on a K-rick Pullman clay loam.

Soil pH dropped from 5.8 in the 0-50 mm to 4.3 in the 150-250 mm NT soil profile in the CW cropping system. The high pH in the 0-50 mm layer of the CW soil was due to the more frequent applications of lime, necessitated by the high nitrogen rates applied. The low values in the 150-250 mm soil profile were due to insufficient mixing of the soil. Both these values may affect the growth and yield of wheat plants (Archer, 1988) and indicate that surface applications of lime were not effective to adjust the pH of these soils in a CW cropping system. Soil

pH values of 5.8 (KCl) may also enhance root diseases (Hornby, 1985) and increase volatilization of surface applied ammonium fertilizers (Tisdale *et al.*, 1993).
Where NT was used to produce wheat in rotation with legume pastures soil pH and P showed no gradient with soil depth due to lower levels in the 0-50 mm and higher levels in the 150-250 mm soil layer. This diference between the CW and PW cropping system may be due to a combination of the lower pH in the 0-50 mm layer of the PW soil which will increase the solubility of phosphorus (Thomas, 1986) and the better soil porosity found after long periods of pastures (Francis and Knight, 1993), which will enhance the movement of soil nutrients.

CONCLUSIONS

No-tillage systems resulted in a build-up of soil chemical properties in the 0-50 mm soil profile, but resulted in lower levels in the deeper soil layers when compared to conventional mouldboard ploughing. In high yielding, continuous cropping areas where high levels of fertilizer were applied annually, this gradient may reduce the sustainability of no-tillage on shallow, stony sandy loam soil. These problems can be overcome by either shallow tine tillage, or inducing cropping systems where wheat is rotated with legume pastures, which reduces the need for high levels of nitrogen fertilizer and frequent liming and improves soil structure.

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Table 1. Distribution of chemical properties with depth in a sandy loam under conventional mouldboard and discploughing (MDT), tine tillage (TT) and no-tillage (NT) conducted for 17 years in two crop rotations.

Tillage method	Soil depth (mm)	pH (KCl)	P (mg kg^{-1})	K (mg kg^{-1})	OM (%)	Total N (%)
CONTINUOUS WHEAT						
MDT	0-50	4.6	62	97	1.07	0.060
	50-150	4.6	59	82	1.11	0.058
	150-250	4.7	58	81	1.04	0.058
	MEAN	4.6	60	80	1.07	0.058
TT	0-50	4.8	67	119	1.66	0.078
	50-150	4.9	64	86	1.35	0.065
	150-250	5.0	58	77	1.02	0.048
	MEAN	4.9	63	94	1.34	0.063
NT	0-50	5.8	95	185	1.92	0.100
	50-150	4.9	73	123	1.10	0.050
	150-250	4.3	65	95	0.77	0.040
	MEAN	5.0	78	134	1.26	0.063
LSD_T(0.05):	T	0.4	6	12	0.13	NS
	T x D	1.1	12	26	0.21	0.02
Pasture Wheat						
MDT	0-50	4.7	83	143	0.86	0.062
	50-150	4.4	78	86	0.89	0.058
	150-250	4.7	89	105	0.83	0.060
	MEAN	4.6	83	111	0.86	0.060
TT	0-50	5.1	80	199	1.91	0.125
	50-150	4.8	77	140	1.34	0.110
	150-250	4.8	83	122	0.77	0.065
	MEAN	4.9	80	154	1.34	0.100
NT	0-50	5.2	74	192	2.13	0.140
	50-150	5.0	69	116	1.09	0.100
	150-250	5.1	72	109	0.69	0.060
	MEAN	5.1	72	139	1.26	0.100
LSD_T(0.05):	T	0.4	8	30	0.16	0.020
	T x D	0.8	NS	72	0.62	0.021

OM = Organic Material
T = Tillage
T X D = Tillage X Depth

HYDROLOGIC ASSESSMENT OF SOILS CONCERNING THE CAPABILITIES AND RISKS FOR AGRICULTURAL USE IN THE NORTH-EAST GERMAN LOWLANDS

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ABSTRACT

Based on available medium-scale soil and hydrologic data and the current pattern of land use, the potentials and risks of agricultural land use were evaluated for a region with lower precipitation (450 to 550 mm/a). The aim was to obtain information about the suitable land use strategy in this region. The land use capabilities were assessed in terms of available soil water supply of the root zone (water storage capacity and capillary rise), precipitation, and a soil quality index (Ackerzahl). The risk for water pollution from agricultural land use was assessed in terms of the annual seepage rate and the turnover of seepage water in the root zone. Further, a medium-scale classification system was developed and the results are presented of a large-scale analysis to describe the regional potential of the subterranean transport of diffuse nitrogen loads from the agriculturally used area to surface waters in the whole territory of the North-east German Lowlands (about $7.2*10^4$ km²). Because of their special hydrologic conditions, fertile soils of the great river lowlands are often well-suited for agricultural and arable land use, and the risk of water pollution is relatively small. At sandy and loamy moraine soils the capabilities for arable use are small, but there is little risk of water pollution, if only the groundwater table is sufficiently deep and no water courses are neighboring. At drained loamy soils without barraging facilities, as well as in the small river valleys with their intensive interaction between ground and surface waters, there are considerable risks of water pollution.

INTRODUCTION

Knowledge of capabilities and risks of land use is necessary for landscape planning purposes. In the temperate climate, agriculture is an important branch of land use and largely depending on soil hydrologic conditions. Two studies were carried out recently on medium and large scales to assess the side effects of agricultural land use to the landscapes of the North-east German Lowlands as related to soil, hydrologic and geologic conditions. The aim of these analyses was to clarify, whether intensive land use is of negative impact on the quality of ground and surface waters of a sub-region, and in what manner this impact varies regionally and maybe temporally. From these results conclusions should be drawn on suitable land use patterns on the one hand, and long-term effects of the intensified agriculture during the last three decades on ground and surface water pollution on the other hand.

I. ANALYSIS OF POTENTIALS AND RISKS OF AGRICULTURAL LAND USE

MATERIALS AND METHODS

The study was conducted in a region of about 2,100 km² east of Berlin. It is covered by moraine soils of the latest glacial and of alluvial river lowland soils. The climatic situation is characterized by an annual precipitation of 450 to 600 mm and a mean temperature of 8.3 °C.

Parameters

To evaluate the hydrologic capabilities of land use and the risks of agriculture for pollution of ground and surface waters, a reliable medium-scale set of parameters and an algorithm to compute it from available soil and hydrologic basic data had to be developed.

The plant available soil water capacity of the root zone (Wpfl) is the crucial parameter to assess the soil quality for plant production. It consists of the water storage capacity and an additional proportion of capillary water supply in soils with shallow water tables. The Wpfl corresponds with crop yields and may be computed from the basic data field capacity, wilting point, depth of the root zone, and water table height (1, 2). A further used complex parameter of the soil quality is the index of the soil basic mapping and evaluation (Ackerzahl) ranging from 7 (worst soils) to 100 (most fertile soils).

The risks of agriculture for groundwater pollution by agrochemicals may be characterized by three important parameters. The first one is the annual seepage (groundwater recharge) rate. Its measurement is difficult, but calculation is possible from soil and climatic data and land use patterns (1, 3).

The second one, the annual translocation depth of seepage water, may be computed as the ratio of groundwater recharge rate and soil field capacity neglecting preferential water flow (4, 5). The third one, the annual turnover of seepage water in the root zone, may be calculated as seepage rate divided by the field capacity of the whole root zone (5). This parameter gives an impression of the ability of soil and plants to use and re-use the solutes from seepage water.

Algorithm

Soil and hydrologic basic data from soil profiles and medium-scale maps were condensed to a grid of 2 * 2 km^2 elements to eliminate noise and to make the data processable and the computational results readable. A cluster procedure was applied to form areas of similar parameter values.

RESULTS AND DISCUSSION

Five groups of different land use after Table 1 and Figure 1 were classified. The values show the differences within the moraine soils (groups 1 to 3) to be relatively small, whilst the alluvial soils of groups 4 and 5 are very different from them. The loamy and clayey soils of the river lowland area are characterized by medium to good suitability for agricultural production. Though the water storage capacity is limited, additional capillary supply from the ground water may provide a sufficient level of crop yields. As the seepage rates are very small and

Table 1: Centroids of parameter values of the clustered groups (arable land)

Parameter	Group 1	Group 2	Group 3	Group 4	Group 5
Soil water capacity of the root zone (mm)	43	50	58	116	225
from that: water storage capacity (mm)	43	50	58	100	98
capillary water supply (mm)	0	0	0	16	127
Soil quality index (Ackerzahl)	28	31	34	49	50
Annual seepage rate (mm)	217	202	172	91	49
Annual translocation depth of seepage water (cm)	128	103	76	32	15
Turnover of seepage water in the root zone (%/a)	416	282	186	44	18
Slope of the land surface (1 = levelled to 4 = distinct sloped field parts)	3.8	3.5	3.3	1.2	1.0

the field capacity and depth of the root zone are medium, the annual translocation rate is small to very small, and the turnover of seepage water is also very small. That means a small to very small risk for vertical translocating of agrochemicals.

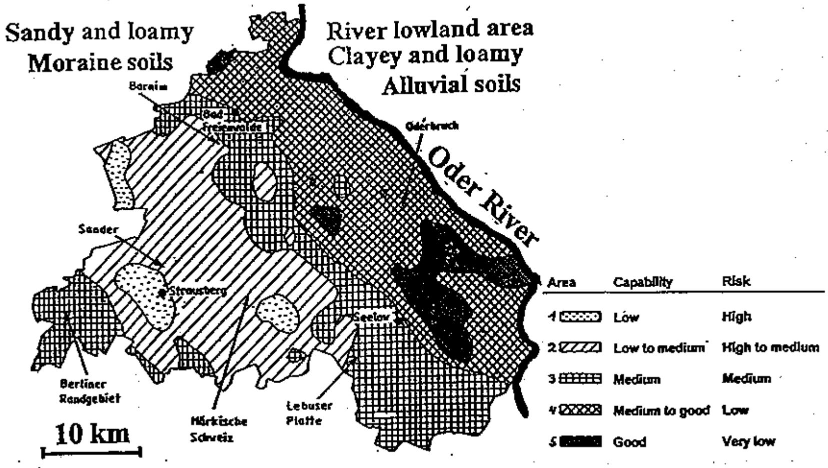

Figure 1: Soil hydrologic assessment of the capabilities and risks of agriculture

II. ANALYSIS OF THE SURFACE WATER POLLUTION FROM AGRICULTURAL NITROGEN LOSSES

MATERIALS AND METHODS

The North-east German Lowlands cover an area of about $7.2 * 10^4$ km² from the Baltic Sea in the North to the southern border of the pleistocene glacier thrust. The study was limited to the territory of the former GDR. The region is characterized by a mean precipitation surplus of 141 mm/a with slopes from the North-west (230 mm/a) and South (150 mm/a) to the middle (130 mm/a) which is splitted to 139 mm in winter (November to April) and 2 mm in summer (May to October). The area is mainly attached to the watersheds of the Elbe river and the Baltic Sea. At the end of the 80s, a total of about 800 kt/a (230 kg/ha/a) of mineral and organic nitrogen came to the 3.5 million hectares of agriculturally used land producing an N surplus of about 350 kt/a (100 kg/ha/a). Extreme N loads within the agriculturally used area of the 800 farms were detected from less than zero up to more than 200 kg/ha/a. Nevertheless, characteristic N loads of the greater lowland rivers including municipal waste water loads vary between 2.5 and 6.5 kg/ha/a as related to the appertaining overall catchment area. The mean N concentration in the upper aquifer of the North-east German Lowlands is about 3.5 mg/l which is quite well corresponding to the N concentration of the rivers.

To clarify the gap between the agricultural N surplus and the N load of the lowland rivers, a large-scale mapping study was carried out based on a medium-scale hydrologic classification of the lowland watershed structures (Figure 2 and Table 2), as well as available soil, topographic, bydrographic, and hydrogeologic information from thematic maps on a medium scale. To define a quantified regional "Potential of nitrogen entry" the specific agricultural N surplus as related to the overall area of each company was multiplied by a parameter derived from the hydrologic types of the attached watershed structures as follows:

Types **BE, GW, Mo**..**0.02**
Types **A1, St, A2**..**0.5**

These values roughly reflect the flow dynamics of nitrates at their underground passage between the soil surface and the surface waters within a typical watershed (Figure 2). The resulting regional pattern of the entry potential is suited to assess the risk of intensive land use in the different landscapes.

Table 2: Typical hydrologic watershed structures in the North-East German Lowlands

A1	(Narrow) brook and river valleys with groundwater exposed fertile plains, partly with peat covers, and short flow distances to the water course
A2	Wide river plains at the middle and lower courses of the Oder and Elbe rivers, partly embanked by dikes, with mostly confining loamy and clayey covers
Mo	Flat to deep, expansive peat wetlands with water barraging facilities for drainage and subirrigation
St	(Mostly underdrained) zones of groundwater distant moraines with flat confining and semi-confining layers and relatively short flow paths to water courses
	"Inner drainage watersheds" in groundwater distant moraines with
GW	– good natural drainage to the groundwater, but long to very long flow paths to water courses
BE	– wide-spread confining subsurface layers, dominant surface runoff and interflow to water holes and lakes without outlet, as well as minimum seepage/groundwater recharge

Finally the total N load transportable with the ground water within the watersheds of several lowland rivers was calculated on the basis of 245 N concentration values measured in 1990 and 1992 in the upper aquifer spread over the whole lowland area. Multiplying these values by the regionally averaged long-term groundwater recharge rate provides information concerning the actual contribution of diffuse N loads to the surface water pollution.

RESULTS AND DISCUSSION

Figure 3 gives an impression of the regional pattern of the N entry potential and its basic parameters. A distinct change is visible from the high N surplus at the agriculturally used area in the districts north, east and south of Berlin to the higher N entry potential in the western part of the lowlands. It is caused by the pattern of forest and agricultural land use on the one hand and the varying relation between retardation/retention disposed and N output areas on the other hand. To the north the N surplus decreases because of the increasing part of loamy soils and, to the north-west, the higher precipitation which provide better capabilities of agricultural land use with higher yields. Some results of Part I. of this paper are reflected on the large scale once more.

Table 3: Calculated total N load transportable via ground water

Catchment	Area	c_N	Number of	specif. N load (kg/ha)		N load
	(km²)	(mg/l)	samples	Winter	Annum	(t/a)
Oder/Neiße	5,300	1.62	18	1.76	1.66	880
Rivers remaining	16,600	2.79	41	1.40	1.52	2,524
Baltic Sea	**21,900**	**2.51**	**59**	**1.49**	**1.55**	**3,404**
Havel (excl. Spree)	13,581	2.45	39	3.09	2.95	4,006
Spree	8,188	2.26	33	2.70	2.61	2,137
Schwarze Elster	4,656	3.55	27	4.53	3.94	1,834
Rivers remaining	23,244	5.31	87	5.46	5.70	13,240
Elbe	**49,669**	**3.86**	**186**	**4.27**	**4.27**	**21,217**
NE-Germ. Lowlands	**71,569**	**3.53**	**245**	**3.43**	**3.44**	**24,621**

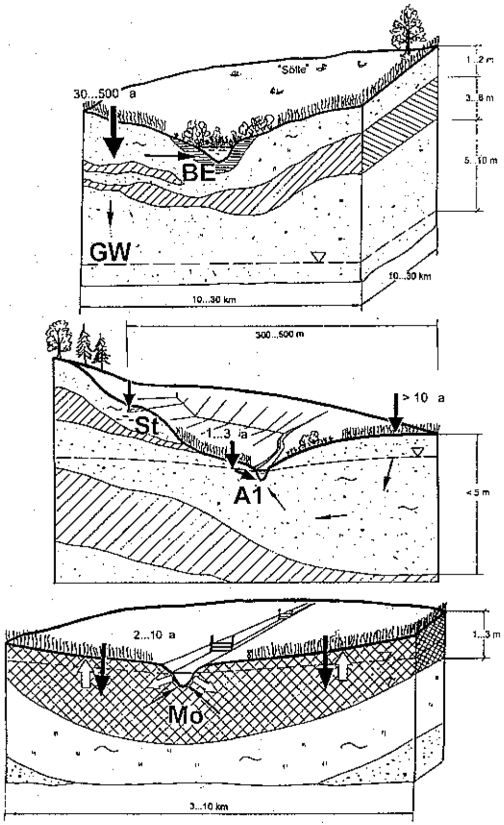

Figure 2: Structures of hydrologic watershed types

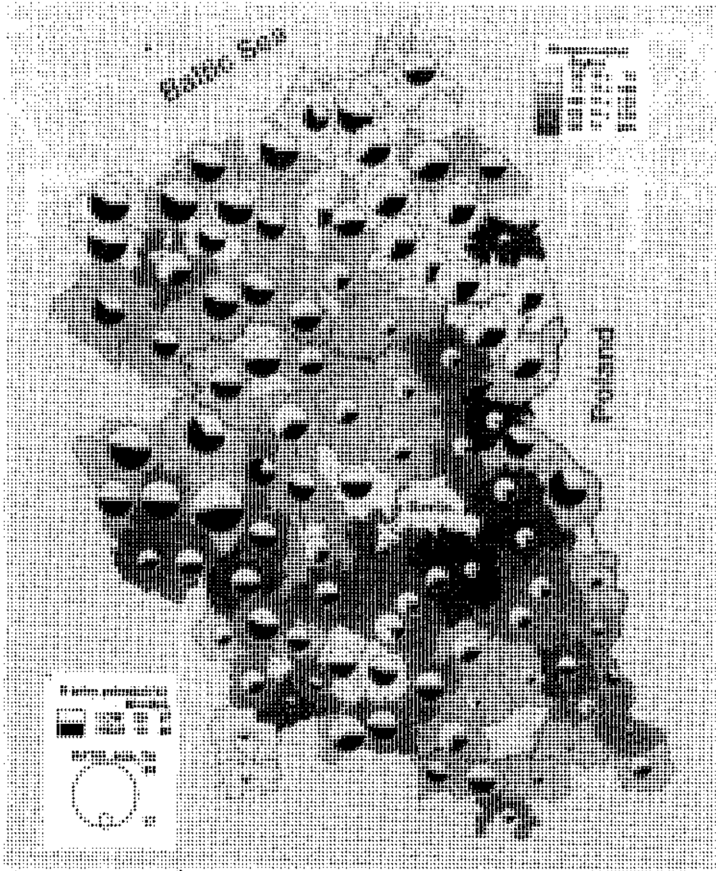

Figure 3: Nitrogen surplus 1989 at agriculturally used area (AUA) of districts, ratio AUA/Total area (TA), and distribution of AUA to sub-regions with low resp. high N entry potential

Table 3 shows the calculated total N loads which are currently transportable via ground water from agricultural sources to the surface waters.

The diffuse N load from the agriculturally used area to lowland rivers at the subterranean path is determined by the agricultural N surplus, the rate of groundwater recharge, the flow distance, difference in hydraulic heights and flow resistances along the transport path, as well as the hydrochemical fate of the traveling N species.

Traveling times along the underground path to the leaving point at the water course vary between hydrologically typical regions from weeks/months (types A1, St), over years/decades (types A2, Mo), up to centuries (types GW, BE). Therefore the actual N loads of water courses result from output events which date back months, years, or decades. Nevertheless, they come from sites covering probably 20 to 25 % of the lowland territory since regions with traveling times of more than 30 years do not share in rising N loads of the lowland rivers up to now. Changes in land use or fertilization act in the lowland rivers only after the corresponding time lag and, as a result of the different flow paths, timely superimposed. Today there is no clarity whether the maximum N load of water courses from the past decades with maximum N fertilization is already reached. But distinctly decreasing N loads of the larger lowland rivers as a result of a reduced agricultural N surplus are expected not before the turn of the millennium.

CONCLUSIONS

The results of the medium-scale soil hydrologic classification and the large-scale geohydrological mapping study provide relative information on the capabilities and risks of agricultural land use depending on the chosen criteria and algorithms. Investigation in the behaviour of the most sensitive parameter "plant available soil water capacity of the root zone (Wpfl)" is a task of further soil hydrologic research. The regional pattern of the N entry potential has been proven to be qualified to explain the detected gap between agricultural N surplus and N load of the lowland rivers. Further research will be directed on experimental systems analysis in sub-catchments of the lowland rivers to investigate the subterranean solute transport on a small scale.

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REDUCED-TILLAGE SYSTEMS ON VERTISOLS IN CENTRAL TEXAS

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ABSTRACT

Vertisol clays present special management and techinical problems for general agriculture and especially for reduced-till and no-till cropping procedures. Fifteen years of field experiments in the Texas Blackland Prairie with wheat (*Triticum aestivum* L.), grain sorghum (*Sorghum bicolor* (L.) Moench), cotton (*Gossypium hirsutum* L.), corn (*Zea mays* L.), and soybeans (*Glycine max* (L.) Merr.) have produced workable technical and management procedures to control weeds, establish crops, apply fertilizers, improve soil properties, and produce acceptable yields. Successful rotation and management practices are reviewed and results are summarized.

INTRODUCTION

Vertisols and high clay soils with vertic properties are characterized by their shrink-swell dynamics upon drying and wetting, which result in the formation of large open cracks. Vertisols are poorly drained because of low infiltration rates and require surface drainage to prevent crop flooding during high intensity rainfall events. Once wet, these soils remain cool and wet for extended periods, especially when covered by crop residues. Expansive carbonatic and montmorillonitic vertisol clay soils, like those on the Texas Blackland Prairie, have friable tilth over a narrow range of water content (approximately 22 to 32%, dry basis). Primary tillage typically produces large clods that require subsequent tillage operations and/or extended weathering to produce an adequate soil sructure for crop establishment. Secondary tillage prior to seeding can cause loss of soil water to levels that are inadequate for seed germination. Tillage to traditional depths of 15 to 20 cm requires substantial expenditures of energy and may not be benefical.

Conservation cropping systems for the Texas Blackland Prairie include:

Modified chisel-till
Chisel-till systems are the predominant "conventional tillage" of the 1990's in Central Texas on vertisols. Tillage is performed to a depth of 15 cm with sweep chisels.. Our modified chisel-till differs from the conventional in three important ways: raised wide beds are used for cropping zones, furrows between the beds provide surface drainage and paths for controlled traffic, and the beds are reformed after annual tillage and then weathered to consolidate and rehydrate before seeding (09).

No-till
A no-till farming system has been designed to address many of the problems encountered when cropping vertisols and other high clay soils (09). The principle of no-till is used to

maintain a crop residue cover to protect the soil from erosion and to reduce pollution with sediment or agricultural chemicals. Machinery, energy, and labor inputs are also minimized. Raised wide beds provide 1.5 m wide areas for two to eight crop rows at various spacings and 0.5 m wide furrows for traffic and drainage, the same as used for Modified Chisel-till (Fig. 1).

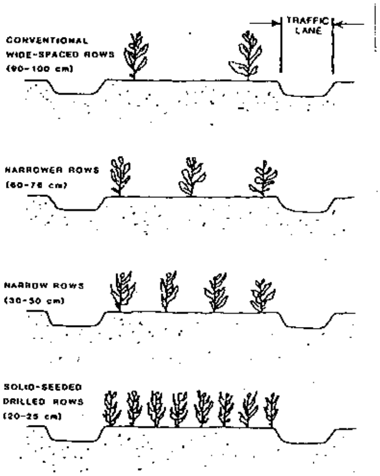

Fig. 1 Beds with 2-8 crop rows

Various aspects of the long-term effects of tillage systems on vertisols are the subject of ongoing studies. The reduction or absence of physical mixing of the tillage layer may produce different soil density, infiltration, and nutrient stratification conditions. Traffic compaction and natural soil consolidation effects are unclear. The high soil pH, 8.0, and increased surface organic matter with no-till make year-around weed control a challenge in our climate.

Vertisols present special problems for machine operation in chisel-till, but especially in no-till systems. The adhesive and plastic characteristics of high water content vertisols below a friable dried surface layer, necessitate the use of depth control wheels on all soil-engaging implements to avoid significant penetration into those untillable layers. Rolling coulters and/or trash rakes are used to cut and/or clear paths through residues for the tools. Rotary scrapers are needed to remove adhesive soil from discs and coulters. Minimal soil and residue cover disturbance is possible with an experimental coulter-nozzle fertilizer applicator with a solid stream nozzle positioned behind a smooth rolling coulter to deposit fertilizer in the coulter slot (08). An experimental triple-disc slot planter has a pnuematic downpressure mechanism and a trash rake to clear a narrow path ahead of each coulter/furrow opener (05). Raised wide beds are reformed by use of an experimental bedder which will operate in residue cover (06).

Conservation cropping systems require year-around weed management. Applications of appropriate herbicides must be timely to achieve effective and economical weed control. Implementation of no-till cropping systems is often accompanied by increased problems with annual grasses and perennial weeds (01). In the Blackland Prairie of Central Texas, johnsongrass [*Sorghum halepense* (L.) Pers.] and browntop panicum (*Panicum fasciculatum* Sw.) are pernicious grasses in both corn and grain sorghum production. Pernicious broadleaf weeds include pigweeds (*Amaranchus* sp.), annual thistles (*Cirsium* sp.), and henbit (*Lamium amplexicaule* L.).

Objectives of this report are to review some published results and current findings to characterize the ongoing research and progress in developing sustainable reduced tillage systems for vertisols.

METHODS AND MATERIALS

Work started in 1979 at Temple, Texas to develop appropriate tillage systems for vertisols. Temple is located at 31°N latitude and 97°W longitude with a mean elevation of 213 m.

Mean annual precipitation is 880 mm with summer droughts. The first study was located on a well drained Austin silty clay (fine-silty, carbonatic, thermic entic Haplustolls), but without raised wide beds. Comparisons were between no-till and chisel-till production of cotton, grain sorghum, and wheat in rotation for three years (03). No-till procedures and weed control management were under development.

The second study emphasized soil nutrient stratifications, plant concentrations of N and P nutrients, and crop yields. The soil was Houston Black clay (fine, montmorillonitic, thermic, Udic Pellusterts) and raised flat wide beds were used with both chisel-till and no-till systems. Wheat, corn, and grain sorghum were rotated annually for two complete cycles over the six year study. There were four fertilizer application rates for each crop. Fertilizer application methods were subsurface knifing and surface sidedressing placements. The plots have been continued since 1983.

The third study is an ongoing comparison of five levels of tillage intensity, with two fertilizer application rates, and a rotation of grain sorghum, corn, and soybeans. The tillage intensity treatments are chisel-till with annual rebedding, secondary disk and field cultivator tillage with annual rebedding, no-till with sweep cultivation between rows, no-till with trash-rake cleared paths along the rows, and no-till "slot planting". Results are not yet available.

Soil core samples were taken in the second study from a chisel-till field one year after tillage and from no-till fields six years and ten years after tillage. Total organic carbon, nitrogen, and phosphorous were determined for 25 mm increments to a depth of 100 mm.

Soil hydrologic properties in the second study were examined after eight years of continuous chisel-till and no-till . Sampling occurred in the fall of 1992 after a wheat crop and was repeated on the same area in the spring of 1993 after sorghum planting. A 10.2 cm diameter automated infiltrometer was used to pond water 5 mm deep until steady state infiltration was approached. After prewetting, ponded infiltration was monitored every five seconds for 1000 seconds. Unsaturated infiltration was measured with a tension infiltrometer at 20, 30, and 60 mm of tension.

Weed control procedures have been developed to obtain the maximum effectiveness from the applied herbicides. Broadcast preemergence and postemergence applications were made with equipment available to producers. An experimental directed sprayer was developed for improved targeting of directed postemergence herbicides in no-till and for variable row widths. It consists of a rear-mounted toolbar with individually flotational spraying units on lightweight runners which move through any loose residue (07).

RESULTS AND DISCUSSION

Preliminary crop rooting, soil properties, and yields

From the first study on Austin silty clay, root length densities in the top 15 cm of soil varied with respect to the three crops and years, but were not different between tillage treatments (04). In this top layer, soil strength and bulk density were equal for chisel-till and no-till in zones not subjected to wheel traffic. Below the 30 cm depth, rooting density was not affected by crop species, tillage, or traffic. Yields of grain sorghum, cotton, wheat, and corn were similar between the two systems (03 and 09).

Fertilizer application and placement

A 10-34-0 solution was applied directly into the seed furrow for all crops and systems as a low rate starter fertilizer. Primary fertilization was applied in one band placed between pairs of 40 to 120-cm spaced crop rows. Crop yield responses were the same from surface bands and subsurface applications (02), but subsurface deposition of fertilizer is preferred because nutrients are placed below the surface zone of maximum microbiological activity and protected from losses in rainfall runoff. Grain yields were similar for most fertilizer application rates between chisel-till and no-till (Fig 2). The coulter-nozzle applicator was found to place 60 to 70% of the nutrients in the top 2 cm of a 3.8-cm deep coulter slot (10).

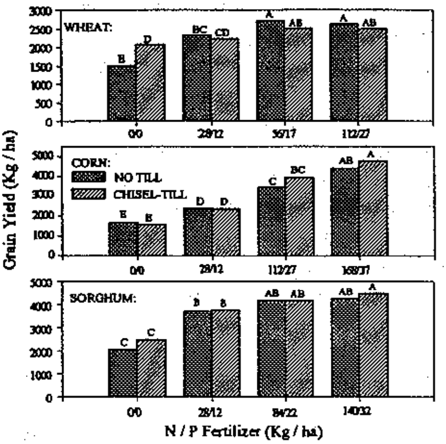

Fig. 2. Yields from six years

Soil organic carbon, nitrogen, and phosphorus distributions

Concentrations of organic carbon, total nitrogen, and total phosphorus were greater near the surface in the no-till fields 6 years (NT-6) and 10 years (NT-10) after tillage than with annual chisel-till (T-1) (11). These nutrients decreased rapidly with depth (Table 1). In contrast, the concentrations of all three nutrients were uniform in the surface 100 mm of the soil mixed by chisel-till (field T-1), one year after tillage. Carbon/nitrogen ratios were largest in T-1, due to incorporation of residues into the soil profile.

Table 1. Soil nutrient distributions for three fields.

Depth Range	Field T-1	Field NT-6	Field NT-10
(mm)		Total Phosphorus (%)	
0-25	0.059 A#	0.074 B w	0.093 C x
25-50	0.060 A	0.061 A x	0.080 B x
50-75	0.058 A	0.058 A xy	0.076 B xy
75-100	0.058 A	0.053 A xyz	0.076 B xy
		Total Nitrogen (%)	
0-25	0.121 A	0.147 B w	0.165 C w
25-50	0.120 A	0.122 A x	0.158 B x
50-75	0.121 A	0.116 A xy	0.152 B x
75-100	0.119 A	0.114 A xy	0.145 B xy
		Organic Carbon (%)	
0-25	1.57 A	1.67 A w	2.02 B v
25-50	1.56 B	1.43 A x	1.77 C w
50-75	1.57 B	1.40 A xy	1.69 C wx
75-100	1.53 B	1.34 A xyz	1.58 A yz

Different letters (w,x,y,z) denote different values within a column and different letters (A,B,C) within a row denote different values between columns, at 5% significance by Tukey's LSD test.

Soil hydraulic properties
Water infiltration rates were not different between chisel-till and no-till crop beds after crop harvest, due to seasonal wetting, drying, and soil cracking (Fig. 3). Infiltration was lower in controlled-traffic furrows than in crop beds, especially in no-till furrows which had not been tilled for eight years. Spring season infiltration rates were higher for no-till than for soil which had been chisel-tilled six months prior to sampling (Fig. 4). Tillage and winter season weathering apparently disrupted soil pore and crack continuity and caused soil reconsolidation and sealing which reduced infiltration.

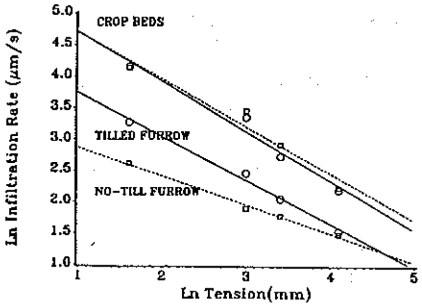

Fig. 3. Infiltration one year after tillage, sampled after 1992 wheat crop.

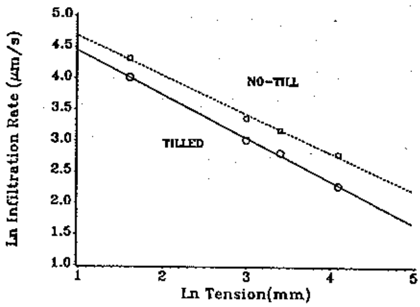

Fig. 4. Infiltration 6 months after fall season tillage.

Weed control
Weed control in the field studies was accomplished with commercial herbicides applied preemergence and/or post emergence within the crops or during the fall fallow season. Johnsongrass was the most pernicious weed in the cropping systems. In grain sorghum fields, rhizome johnsongrass control was excellent with fall applications of glyphosate (Roundup[TN]), but poor with spring applications. In cotton or soybeans, fluozifop (Fusilade[TN]) applied postemergence over-the-top provided control of annual and perennial grasses. In corn, nicosulfuron (Accent[TN]) applied postemergence controlled johnsongrass and browntop panicum, while primisulfuron (Beacon[TN]) conrolled johnsongrass and selected broadleaf species. Weed control with herbicides required close management for successful and profitable control.

CONCLUSIONS

Modified chisel-till appears to be a functionally useable system for continuous crop production on vertisols. Although it is similar to local conventional practice, the inclusion of raised wide beds and controlled traffic reduced the number of field trips, provided surface drainage, and localized compaction from traffic. Modified chisel-till is an intermediate conservation practice between conventional tillage and no-till.

The no-till system described for vertisols in Central Texas has proven to be manageable and sustainable on the same experimental fields for as long as 15 years. Yields are maintained, nutrients and organic carbon become stratified, and water infiltration is seasonally improved.

TN - Trade Name describes methods and is not a recommendation over other products.

Weed control management practices change with the introductions of improved herbicides and with changes in predominant weed species. Experimental implements enable field procedures on vertisols until commercial units are available. It is anticipated that modifications of this no-till system will he adaptable to vertisols in other regions and to other soils, especially to high clay soils.

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A SURVEY OF CROP RESIDUE MANAGEMENT IN THE USA

Daniel McCain, ISTRO member

ABSTRACT: During the last decade, there has been increasing use of crop residue management systems in the USA. These CRM systems begin with the selection of crops that produce sufficient quantities of residue and may include limited secondary harvest of residue. Crop residue management includes all field operations that affect the amount, orientation and distribution of residue. Progress in this area is helping farmers make greater profits, protect land from erosion, improve water quality and stay in compliance with government farm programs. Since 1982, the Conservation Technology Information Center (CTIC) has conducted annual surveys of conservation tillage practices in 3,092 counties covering all of the cropland in the USA. Tillage practices surveyed include no-till, ridge-till, and mulch-till systems (conservation tillage types with 30% or more surface cover after planting), and systems with surface residue levels of 0-15% and 15-30%. The 1993 cropping year figures showed the strongest trend toward higher use of crop residues since the survey began. The CTIC survey found an increase in all forms of surface residue management above 15% cover. The most dramatic increase was a two and one-half times increase in no-till acreage in the last five years. This paper will review USA trends in crop residue management categories and the three distinct conservation tillage types.

With its creation in 1982, the Conservation Technology Information Center (CTIC) began the process of collecting conservation tillage information. The respondents were USDA employees at each of the 3,092 counties in the USA. The leadership at the local level was vested in the US Soil Conservation Service with assistance from other agencies. For the first seven years, the only categories collected were conservation tillage types for the eight biggest crops. This original list of conservation tillage types included no-till, ridge-till, strip-till, mulch-till and reduced-till. All tillage types were expected to have at least 30% surface cover after planting where water erosion is the primary hazard, or 1,000 pounds of flat small grain residue (SGE) equivalent during the critical wind erosion period.

By the late 1980's the advance of federal farm bill planning had necessitated a change in the survey to reflect trends in residue levels below what CTIC had been collecting. In 1989, CTIC changed the survey to include two new levels that would not fit the conservation tillage (30%) minimum requirement. Now the full spectrum of conventional tillage (0-15%) and minimum tillage (15-30%) could be represented. A change in definitions allowed the incorporation of the strip-till and reduced-till practices into no-till or mulch-till categories. This left the survey with five columns--same as the original list.

Daniel McCain has been the CTIC Field Specialist since 1987. The Conservation Technology Information Center (CTIC) is a national soil conservation and water quality information center located at 1220 Potter Drive, West Lafayette, Indiana 47906. Funding to operate this Center comes mostly from corporate (agribusiness) members and government sources.

Conservation Tillage Definitions and Types of Systems

Crop Residue Management (CRM) — A year-round system beginning with the selection of crops that produce sufficient quantities of residue and may include limited secondary harvest of residue. CRM includes all field operations that affect residue amounts, orientation and distribution throughout the period requiring protection. Site-specific residue cover amounts needed are usually expressed in percentage but may also be in pounds.

Conservation Tillage — Any tillage and planting system that maintains at least 30% of the soil surface covered by residue after planting to reduce soil erosion by water. Where soil erosion by wind is the primary concern, any system that maintains at least 1,000 pounds per acre of flat, small grain residue equivalent on the surface throughout the critical wind erosion period.

Types of Conservation Tillage

1. **No-till** — The soil is left undisturbed from harvest to planting except for nutrient injection. Planting or drilling is accomplished in a narrow seedbed or slot created by coulters, row cleaners, disk openers, in-row chisels or roto-tillers. Weed control is accomplished primarily with herbicides. Cultivation may be used for emergency weed control.

2. **Ridge-till** — The soil is left undisturbed from harvest to planting except for nutrient injection. Planting is completed in a seedbed prepared on ridges with sweeps, disk openers, coulters, or row cleaners. Residue is left on the surface between ridges. Weed control is accomplished with herbicides and/or cultivation. Ridges are rebuilt during cultivation.

3. **Mulch-till** — The soil is disturbed prior to planting. Tillage tools such as chisels, field cultivators, disks, sweeps or blades are used. Weed control is accomplished with herbicides and/or cultivation.

Other Tillage Types — Tillage and planting systems that may meet erosion control goals with or without other supporting conservation practices (i.e., strip cropping, contouring, terracing, etc.).

4. **15-30% Residue** — Tillage types that leave 15-30% residue cover after planting or 500 to 1,000 pounds per acre of small grain residue equivalent throughout the critical wind erosion period.

5. **Less Than 15% Residue** — Tillage types that leave less than 15% residue cover after planting, or less than 500 pounds per acre of small grain residue equivalent throughout the critical wind erosion period.

Crop Residue Management... Gaining Ground In The 90's

CTIC-Alliance For Crop Residue Management

Crop Residue Management in the USA -- "a mega-trend of the 1990's"

For the United States of America in the last decade, technologies have evolved that encourages the transition from conventional moldboard tillage to crop residue management (CRM) systems. These technologies translate to favorable economics. The total CRM acreage (15% or greater cover after planting) has shown an increase for the last five years. Progress in this arena is helping farmers make greater profits, protect land from erosion, improve water quality and stay in compliance with the USDA farm programs.

US planted cropland acreage aggregated in CTIC's ***1993 Crop Residue Management Survey*** shows strong trends toward higher use of the three **conservation tillage** types:

No-till showed the most dramatic increase of any tillage type for each of the past five years. This practice has grown from 14 million acres nationally (1989) to nearly 35 million acres Regionally the greatest acreage of no-till is found in the Midwestern states. Percentage of crop acres planted no-till is highest in the Appalachian states. No-till is growing rapidly in many areas because of the efficiency of the system. Farmers are attracted to the fuel and machinery savings but even more attracted to the time savings. New technologies are emerging more rapidly for no-till than any other tillage option.

Ridge-till advances have drawn into a narrower band in the western corn belt and central plains states. Formerly the flat black soils of the eastern corn belt were also lands popular for ridge-till systems. Now with the advance of no-till planting techniques and where corn/soybeans and row crop/small grains rotations are prominent, ridge-till is diminishing. Where continuous corn is common, and especially where furrow irrigation is a viable option, ridge-till is still growing. Nationally there are 3.5 million acres in this practice.

Mulch-till is the largest of the three conservation tillage types. National growth has been relatively slow since 1989, however there has been a consistent 2 million acres increase for the past four years. Much is vested in the mulch-till practice for farmers with conservation compliance commitments. Residue levels required on "highly erodible land" for meeting USDA farm bill compliance could mostly be met by farmers using mulch-till applications. This is especially vital for plan compliance in the western states.

When one of the survey's five tillage categories declines, another accelerates. This is especially true with the strong transition to no-till soybeans in the midwestern states. The popularity of narrow row soybeans drilled directly into last year's corn stalks has proven its efficiency to many farmers. Watch next for no-till cotton planting to rapidly increase.

As the January 1, 1995, deadline for farm bill compliance rapidly approaches, some areas of the USA will have an easy time of meeting the goals, others will not. Farmers are accepting the challenges and learning new ways of applying crop residue management--

FOR LAND'S SAKE!

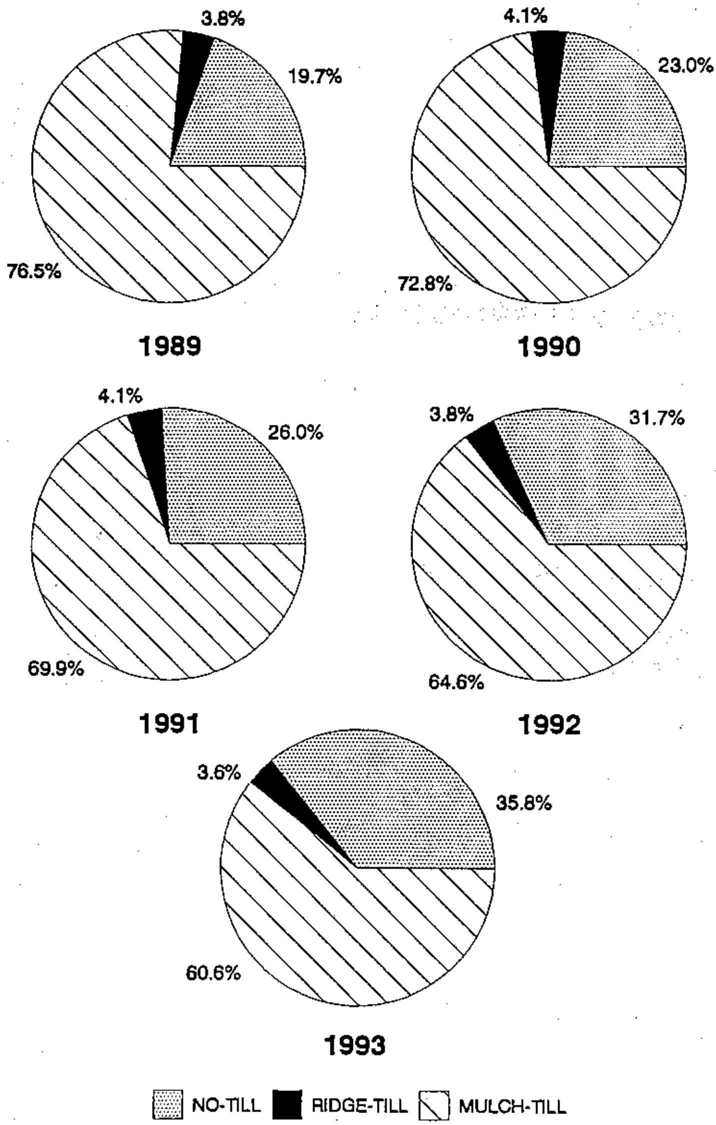
Conservation Tillage and Other Tillage Types
In the United States -- 1989-1993

(percent of planted acres under each category)

Conservation Tillage Types - over 30% cover after planting	**1989**	**1990**	**1991**	**1992**	**1993**
No-Till	14,148,144 (5.06%)	16,861,810 (6.00%)	20,610,658 (7.33%)	28,078,484 (9.92%)	34,824,650 (12.52%)
Ridge-Till	2,716,275 (0.97%)	3,037,899 (1.08%)	3,234,786 (1.15%)	3,359,054 (1.19%)	3,453,789 (1.24%)
Mulch-Till	54,868,667 (19.62%)	53,344,132 (18.98%)	55,306,285 (19.66%)	57,267,155 (20.24%)	58,871,296 (21.16%)
Conservation Tillage SUB-TOTAL	**71,733,086 (25.65%)**	**73,243,841 (26.07%)**	**79,151,729 (28.14%)**	**88,704,693 (31.35%)**	**97,149,735 (34.92%)**
Other Tillage Types - less than 30% cover after planting					
15-30% cover	70,647,007 (25.26%)	70,997,797 (25.27%)	72,318,727 (25.71%)	73,395,322 (25.94%)	73,156,979 (26.30%)
Crop Residue Mgmt. SUB-TOTAL	**142,380,093 (50.9%)**	**144,241,638 (51.3%)**	**151,470,456 (53.9%)**	**162,100,015 (57.3%)**	**170,306,714 (61.2%)**
0-15% cover	137,274,896 (49.09%)	136,744,289 (48.67%)	129,779,224 (46.14%)	120,809,064 (42.70%)	107,867,151 (38.78%)
US Planted Acres TOTAL	**279,654,989**	**280,985,927**	**281,249,680**	**282,909,079**	**278,173,865**

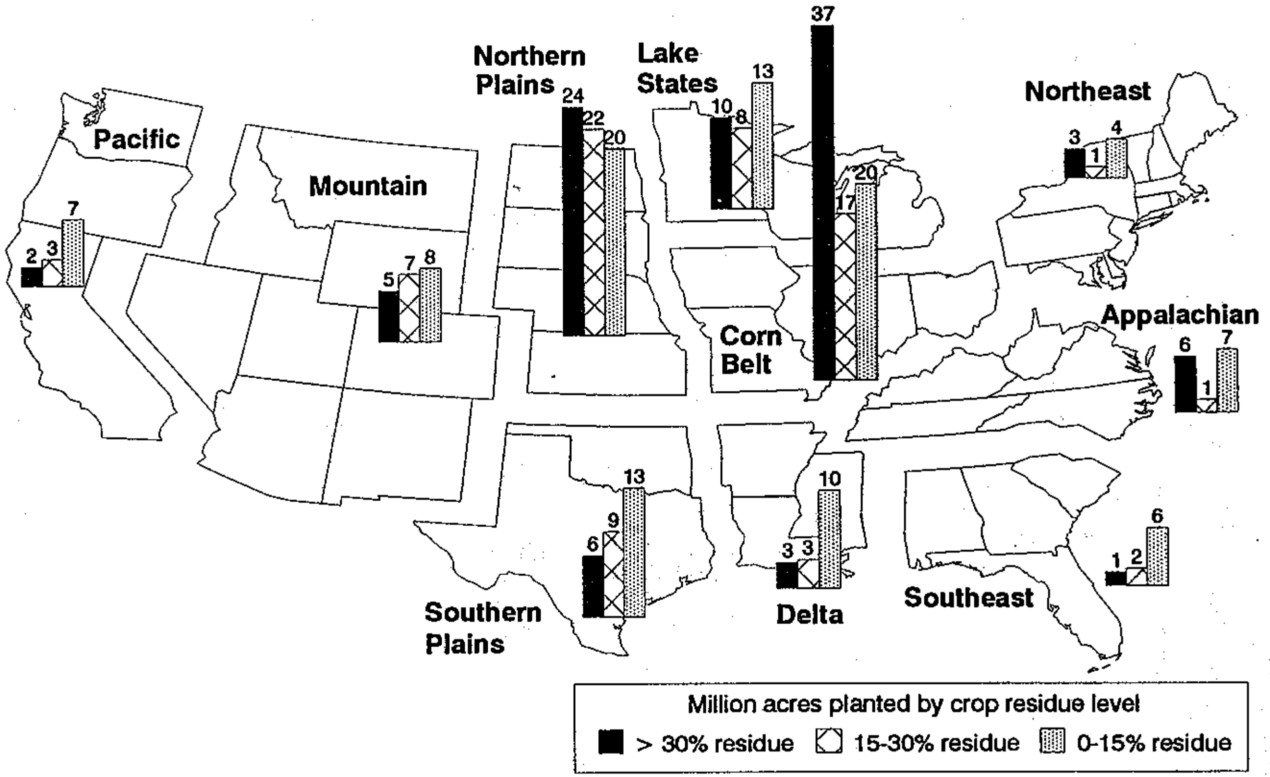
Source: Conservation Technology Information Center (CTIC)
National Crop Residue Management Survey

Acres Planted W/Conservation Tillage by Practice
United States (1989-1990-1991-1992-1993)



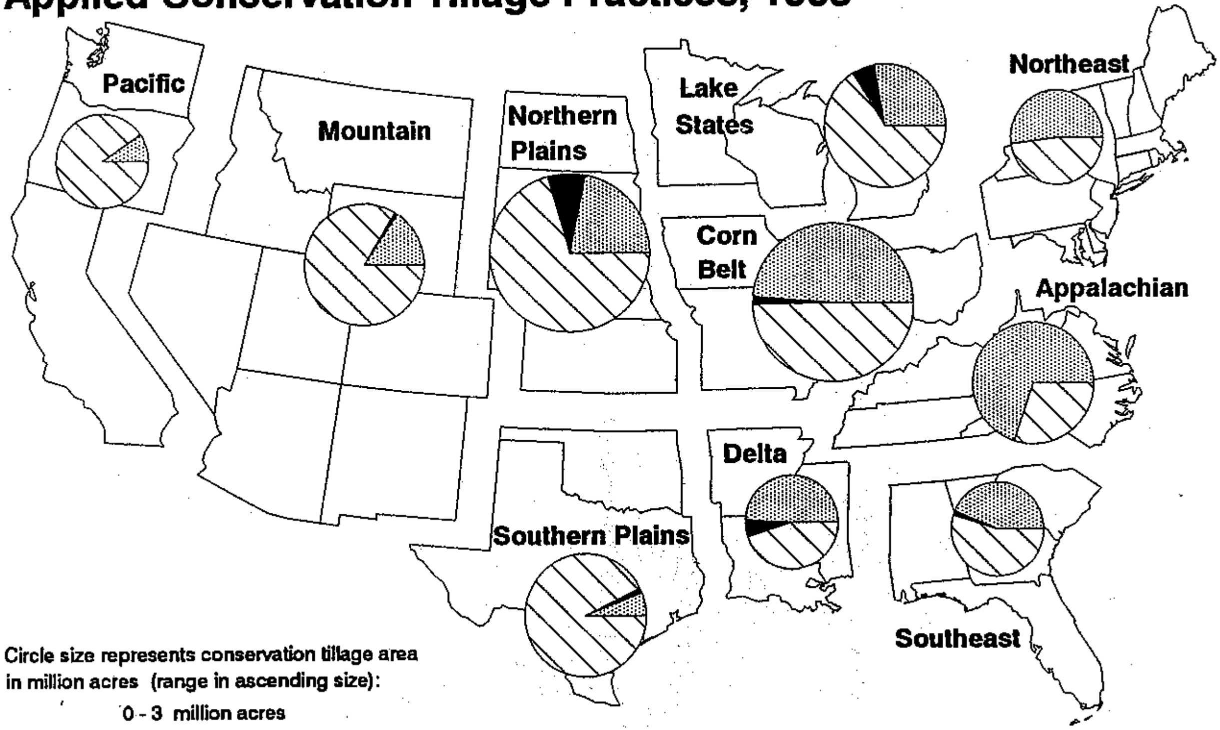
Source: Conservation Technology Information Center data

Crop Residue Levels on Planted Acreage by Region, 1993



Source: Conservation Technology Information Center data.

Applied Conservation Tillage Practices, 1993



Circle size represents conservation tillage area in million acres (range in ascending size):

0 - 3 million acres

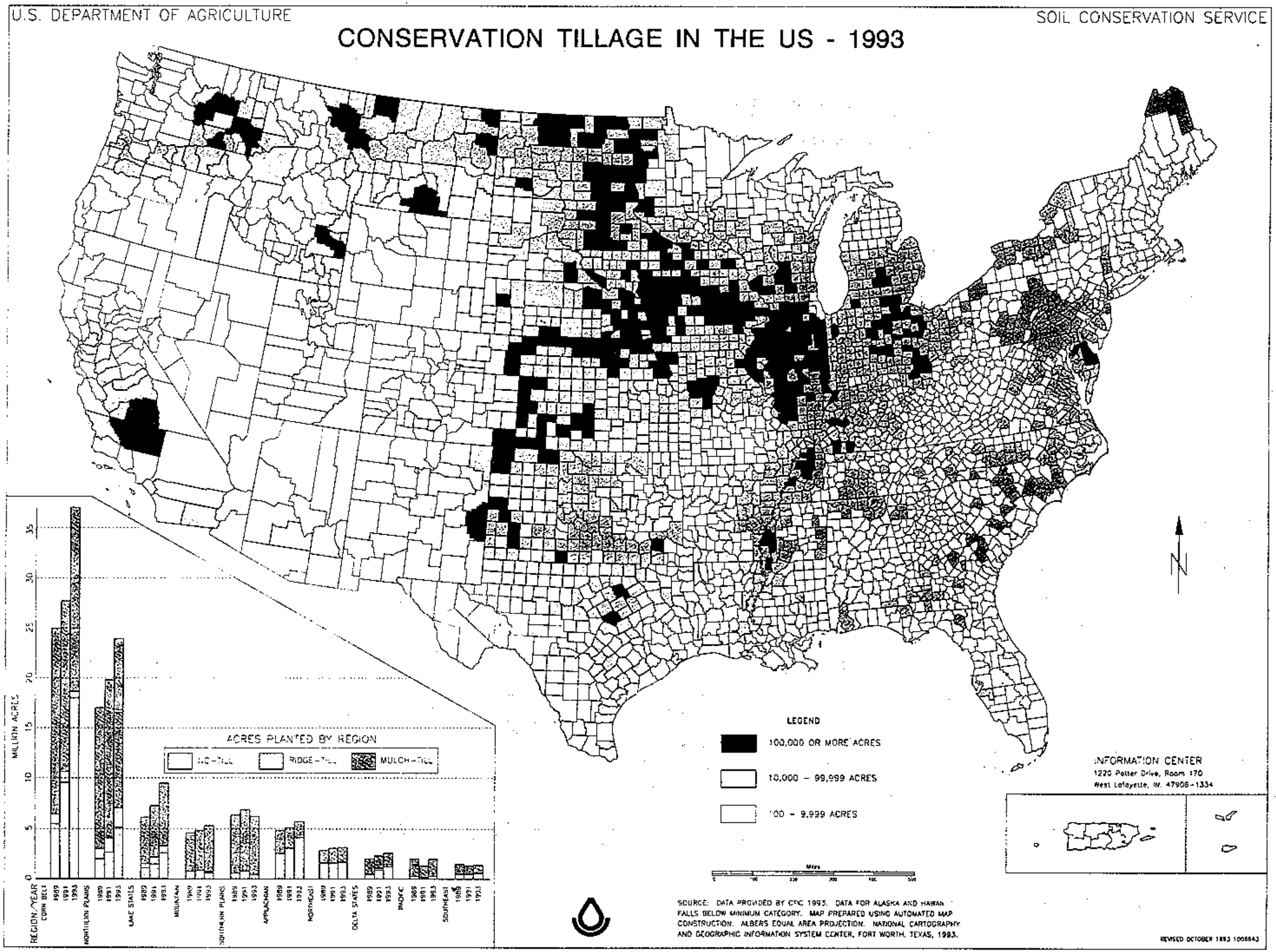
4 - 10 million acres

24 - 37 million acres

Conservation tillage practice shares by type

No-Till Ridge-Till Mulch Tillage

Source: Conservation Technology Information Center data



USDA, SCS, NATIONAL CARTOGRAPHY & GIS CENTER, FORT WORTH, TX, 1993

YIELD RESPONSE OF MAIZE HYBRIDS TO LONG-TERM APPLICATION OF NO-TILLAGE

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ABSTRACT

Relative grain yields of different maize (*Zea mays* L.) hybrids are thought to be similar under plow tillage (PT) and no-tillage (NT). However, most studies have been conducted on sites where a history of NT, and associated pest pressures and nutrient redistribution in the soil, has not yet been established. The objective of our study was to assess grain production, in established PT and NT fields, as affected by the interaction between tillage system and genetically diverse maize hybrids. Field experiments were conducted at two locations in Ohio during 1990, 1991 and 1992. Twelve hybrids were compared in adjacent PT and NT fields managed similarly for the previous five years except for tillage. For grain yields, significant differences ($P < 0.05$) occurred for all main effects (locations, years, tillage and hybrids). Two years out of three, hybrids that yielded well under PT also yielded well under NT. In 1990 and 1991, only the location by hybrid interaction was below or near the 0.05 level of significance. In 1992, a very favorable growing season, all two-way interactions were significant. The significant tillage by hybrid interaction revealed that some hybrids performed better under NT than PT, even in the very poorly drained Hoytville soil.

INTRODUCTION

Conservation tillage systems are defined as having at least 30% or more of the soil surface covered with residue after planting. Conservation tillage practices are being applied to ever increasing amounts of land in the United States because of the need for improved erosion control [1]. Improved economy of energy and time are additional reasons farmers are adopting conservation tillage practices.

No-tillage provides the greatest erosion control on steeply sloping soils and is the recommended conservation tillage practice for production of maize on such soils [2]. No-tillage grain yields of maize on sloping or well-drained soils have been consistently greater than on poorly drained soils [3-5]. Improved soil physical properties and reduced soil moisture loss from the residue-covered and well-drained NT fields are cited as reasons for this observation [6].

Reasons for lower grain yields on poorly drained soils to which NT is applied are poorly understood but have been attributed to cooler and wetter conditions in the spring, allelopathy, and soil pathogens [5]. Some of the yield reduction associated with continuous NT maize production can be overcome if crops are rotated instead of growing maize every year.

Some studies have indicated that relative hybrid performance is similar across a range of tillage systems [7]. Other studies have shown a very clear tillage by hybrid interaction, although this interaction was often observed on some phenotypic response other than grain yield [8]. Most studies evaluating maize hybrid performance under various tillage systems are conducted on soils that do not have a history of continuous NT application. The results obtained from these studies may not be representative of NT and PT comparisons when conservation tillage practices are maintained on the same soil over several years. Our objective was to evaluate relative performance of maize hybrids, with diverse genetics, to produce grain when grown in different soil types and where NT has been maintained for at least five years prior to when our study was initiated.

Table 1. Maize hybrids used

Brand/Hybrid	Number
Asgrow A626	1
Dekalb DK550	2
Golden Harvest H2532	3
French 250	4
Shur Grow SG836	5
Bird B27	6
Bo Jac 454	7
Good Buddy GB310	8
Leader SX535	9
Voris V2495	10
Bird B66	11
Pioneer 3343	12

MATERIALS AND METHODS

Twelve maize hybrids (Table 1) were grown for three years using PT and NT at Wooster and Hoytville. To assure a range of diverse genetics, all hybrids were selected from previous hybrid trials and differed statistically ($P < 0.05$) in one or more of the following agronomic characteristics: grain moisture content, days to mid silk, plant height, ear height, and test weight. The soils were Canfield silty clay loam (Wooster site) with good internal drainage and Hoytville clay loam (Hoytville site) with very poor internal drainage. Two separate adjacent fields at each site, with a minimum five year history of either PT or NT, were used. Therefore, the tillage variable was not completely randomized but was confined to these fields. However, all management variables except tillage had been identical in the two fields. Soil pH was maintained at 6.5 and soil test P and K were above recommended levels at both locations. Tillage treatments applied to each field were maintained and hybrids were randomized within each of the fields. At the Hoytville site, plowing was conducted in the autumn and spring plowing was practiced at the Wooster site. The PT treatment also included at least one secondary tillage (spring tooth harrow or disk) to a depth of 20 cm. With NT, residue was disturbed only by the planter.

Planting dates and fertilizer additions are described (Table 2). Seed was planted using a commercial planter modified for small plot use. Different seed lots were used each year and germination at room temperature (22°C) was 90% or above in all cases. Weed and insect control were accomplished chemically for both tillage systems. Climatological data for the two locations is shown in Figure 1.

Each year after emergence, plant populations were equalized across an entire site by removing excess plants using a hand hoe. Plant populations at the Wooster site in 1990 were adjusted to 55,100/ha, 66,200/ha, or 79,200/ha and at the Hoytville site the plant populations were adjusted to 55,100/ha and 66,200/ha. In 1991 and 1992 plant populations at both sites were adjusted to 55,100/ha and 79,200/ha. Grain yield was determined by harvesting with a plot combine and all yields are reported on the basis of the grain having 13.5% moisture.

Grain yields were averaged across all plant populations each year and for each site. The grain yields were then analyzed by analysis of variance using a split plot model that included location and tillage as whole plots and hybrid as split plots. Hybrids within whole plots were rerandomized each year.

RESULTS AND DISCUSSION

Climate variations were quite extreme during the three years of the study. During 1991, precipitation was very low and temperatures were above normal. In 1990 and 1992, precipitation in July was very high and temperatures were more moderate. These three years thus provide a test of hybrid yield response to tillage under three very different climatic conditions in Ohio.

Grain yields were at record levels in 1992, at mean levels in 1990 and severely reduced by the drought in 1991 at both locations (Table 3). At Wooster, the three year mean grain yield was higher for NT than for PT. When looking at individual years, only in 1992, when growth

Table 2. Planting dates and fertilizer additions for the Wooster and Hoytville sites

Site	Year	Planting Date	Fertilizer Additions (kg/ha)
Wooster	1990	May 25	170 (in row 19-19-19 at planting) 300 (28% N solution sidedress) 22-P and 170-K (broadcast)
	1991	May 10	170 (in row 19-19-19) 300 (28% N solution sidedress) 73-P and 145-K (broadcast)
	1992	May 14	170 (in row 19-19-19) 270 (28% N solution sidedress) 67-P and 67-K (broadcast)
Hoytville	1990	May 1	112 (in row 19-19-19 at planting) 280 (ammonia, sidedress) 22-P and 112-K (broadcast)
	1991	May 13	112 (in row 19-19-19 at planting) 280 (ammonia, sidedress) 22-P and 112-K (broadcast)
	1992	May 12	112 (in row 19-19-19 at planting) 280 (ammonia, sidedress) 22-P and 112-K (broadcast)

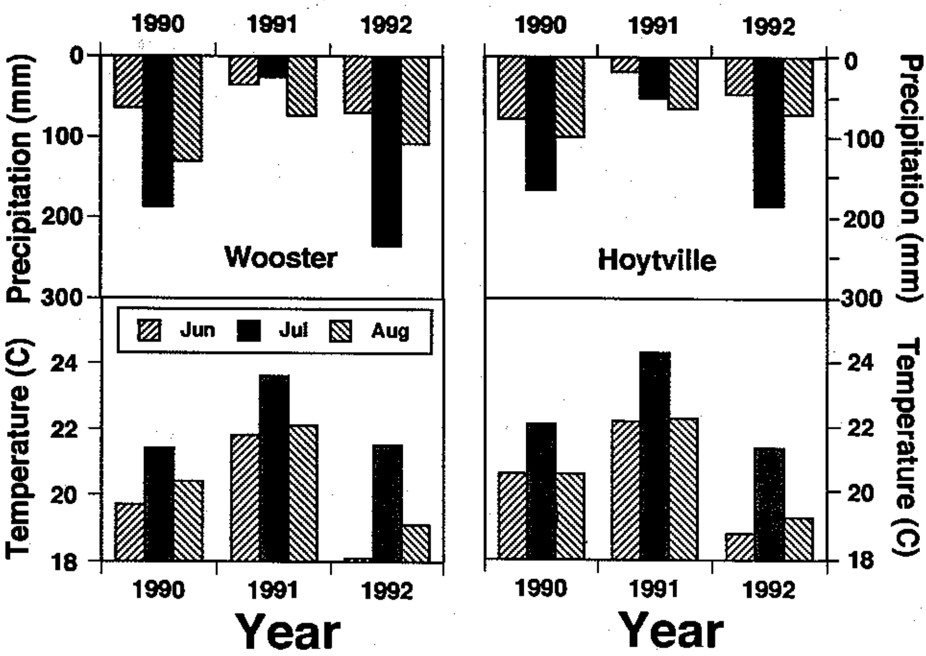

Figure 1. Mean monthly precipitation and temperature at the Wooster and Hoytville sites during June, July and August for the years 1990, 1991 and 1992.

Table 3. Maize grain yield response to location and tillage

Location	Tillage	Year 1990	1991	1992	Means
		Mg/ha			
Wooster	PT	8.65	4.83	10.9	8.09
	NT	10.5	5.46	10.5	8.84
Hoytville	PT	6.84	2.95	9.72	6.52
	NT	6.33	3.83	8.66	6.27
Means	PT	7.71	3.89	10.3	7.28
	NT	8.34	4.64	9.70	7.53

conditions were most favorable and high yields were achieved, were the NT and PT yields similar. This is consistent with numerous reports showing that NT yields in highly permeable, low organic matter soils are higher than PT yields, especially under conditions where water is limiting [3-5]. At Hoytville, only during the very dry year of 1991, was the NT yield higher than the PT yield and the three year average for PT was higher than for NT.

A statistical summary (Table 4) indicates that in all years grain yields were significantly affected by location and tillage. Yields were higher at the Wooster site than at the Hoytville site averaging 8.47 Mg/ha at Wooster and 6.40 Mg/ha at Hoytville over the three year test period. Tillage also significantly affected grain yield with the three year mean being 7.53 Mg/ha for NT and 7.28 Mg/ha for PT. The location by tillage interaction was used as an error term to test for significance of the main effects of location and tillage and is not reported.

Maize hybrids were found to significantly affect grain yields in 1991 and 1992. There were four fewer hybrids included in the test in 1990 and among these eight hybrids there was found to be no significant difference in yield. This lack of difference in grain yield among hybrids at Wooster in 1990 is probably due to the very late planting date.

More important are the evaluations of the interactions. For 1991 and 1992 there was a significant interaction between location and hybrid and the Prob. > F in 1990 was 0.0562

Table 4. Summary of statistical significance of combined analyses of 12 maize hybrids compared under two tillage systems, at two locations and over three years.

Source	1990 df	1990 Prob. > F	1991 df	1991 Prob. > F	1992 df	1992 Prob. > F
Location (L)	1	<0.0001	1	<0.0001	1	<0.0001
Tillage (T)	1	0.0006	1	<0.0001	1	<0.0001
Hybrid (H)	7	0.2984	11	<0.0001	11	0.0001
L x H	7	0.0562	11	<0.0001	11	<0.0001
T x H	7	0.6745	11	0.8353	11	0.0057

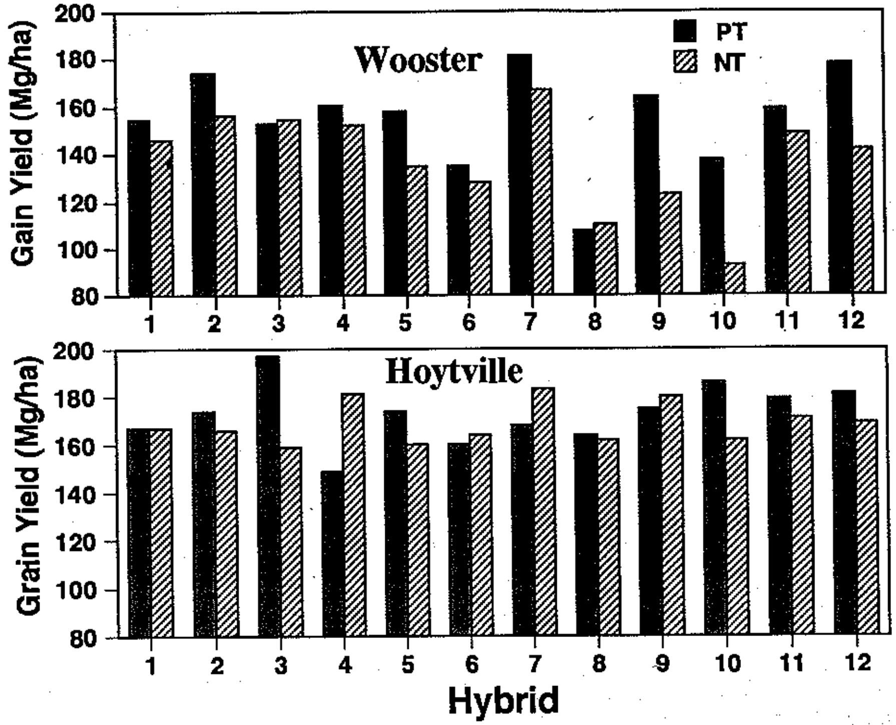

Figure 2. Grain yields of hybrids in 1992 using NT or PT crop production management practices at the Wooster and Hoytville sites.

which was very close to the 5% test level of significance. This is not surprising because of the difference in growing degree days commonly found between Wooster and Hoytville, mean monthly average temperatures and precipitation differences (Figure 1). However, this response was not further evaluated.

Of most interest was the interaction between tillage and hybrid. Our test hypothesis was that we would not observe any differences in performance when hybrids were grown under NT or PT. This was, in fact, observed in 1990 and 1991 where the F test very strongly indicated that hybrids that performed well under one tillage system also performed well under the other tillage system. In 1992, however, when growth conditions were ideal and very high yields were observed, a highly significant interaction between tillage and hybrid was observed. The individual hybrid responses under NT and PT for the Wooster and Hoytville sites are shown in Figure 2. Hybrid 8 responded completely different from the other hybrids at Wooster with the NT treatment outyielding the PT treatment. Hybrids 9, 10 and 12 had higher than expected yields under PT than NT. At Hoytville, Hybrids 4 and 7 had significantly higher NT than PT yields while Hybrids 3 and 10 had higher than expected yields under PT than NT.

CONCLUSION

Grain yields of different maize hybrids varied similarly for both NT and PT during years when yields might have been limited by moisture. This was especially evident for the drought year of

1991. However, when moisture became less limiting and more optimum growth conditions occurred, then some hybrids performed differently when grown using NT versus PT management practices. In 1992, a year of record grain harvest, PT yields were higher than NT yields at both the Wooster site and at the Hoytville site. Under these conditions, genetic differences among hybrids against disease may have had a more dominant role in determining yields than in the drier years when resistant to moisture stress was important. In general, maize yields in the Corn Belt region of the United States are most often limited by moisture and thus selection for high yielding hybrids is weighted towards hybrids that do well under such conditions. Differences among hybrids pertaining to disease resistance may be considered of secondary importance. However in 1992, under the very good growth conditions, these differences became apparent with some hybrids performing better under NT, even in the very poorly drained Hoytville soil. More research is needed to clearly identify the physiological characteristics of those hybrids that performed significantly better when grown under NT as compared to PT management practices.

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SOIL TILLAGE, GREEN COVER CROPS, STRAW AND NITRATE LEACHING IN TWO ARABLE FARMING SYSTEMS

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ABSTRACT

In cereal dominated four field integrated crop rotations on a coarse sandy soil and a sandy loam soil experiment with soil tillage, catch crops and incorporation of straw were conducted over the period 1989-1993. Crop rotation on the coarse sandy soil was potatoe, winter rye, spring barley with a catch crop of rye grass and spring barley with a catch crop of fodder rape. Crop rotation on the sandy loam was winter barley, winter rape, winter wheat and spring barley. A ploughing depth of 20 cm gave significant higher yields than 10 cm ploughing in some crops on coarse sandy soil - especially when a large quantity of straw had to be incorporated. On the sandy loam soil ploughing depth was without influence on the crop yields. Green cover crops and incorporated straw gave significant yield increases in potatoe, winter rye and spring barley with a catch crop of fodder rape on the coarse sandy soil, whereas spring barley with a catch crop of rye grass gave yield decrease. Straw and slurry increased the yield of winter rape and spring barley on the sandy loam soil but in winter barley and winter wheat only trends were seen. Cover crops, straw and slurry decreased the yield during the first 1 to 3 years , but afterwards yield increases were measured in most crops - especially on the coarse sandy soil. Cover crops, straw and slurry reduced nitrate leaching. An undersown rye grass catch crop gave less nitrate leaching than autumn sown fodder rape catch crop. Results of yields as well as nitrogen leaching indicate that the experiments should be continued for several years.

INTRODUCTION

In order to reduce nitrate leaching and increase the N-uptake in plants the Danish Government has stated that 65 per cent of each farms arable area must be grown with winter green cover crops which include autumn sown cereals, grassland and catch crops. Incorporation of green cover crops is not allowed before October 20. On up to 20 per cent of the farms area compensation of 1 ha cover crop with incorporation of 1.6 ha straw is permitted.
At the implementation of the ***law of green cover crops*** there was a need to investigate the influence of cover crops on soil tillage and crop production and also on nitrate leaching. The aims of the project were to investigate the influence of green cover crops on the yields of different crops in two crop rotations and the influence on nitrate leaching on a corse sandy soil.

MATERIALS AND METHODS

The project was conducted in two integrated arable farming systems on a coarse sandy soil at Jyndevad and a fine sandy loam soil at Ødum over the period 1989-1993.
At both sites the experimental plan was conducted in crop rotations with four fields as follows: Jyndevad, coarse sandy soil: 1) potatoe, 2) winter rye, 3) spring barley with an undersown catch crop of rye grass and 4) spring barley with an autumn sown catch crop of fodder rape. Ødum, sandy loam soil: 1) winter rape, 2) winter wheat, 3) spring barley and 4) winter barley.
At both sites the crop rotations were divided into fields of about 1 ha, and the experimental plan was conducted in all of the four fields in each rotation.
The experimental plan is shown in table 1 which also shows the percentage of green cover crops in the treatments.

Table 1. Experimental plan.

	coarse sand Jyndevad	sandy loam Ødum	per cent green cover crops Jyndevad	per cent green cover crops Ødum
<u>Factor 1. Green cover crop *(organic matter)*</u>				
0. No cover crops	+	+	25	75
2. Straw and slurry		+		90
3. Catch crop and straw	+		90	
4. Catch crop, straw and slurry	+		90	

+ *indicates where the treatments were conducted.*

<u>Factor 2. Depth of ploughing</u>
a. Ploughing depth 20 cm
b. Ploughing depth 10 cm

3 - 4 levels of nitrogen were also included in the experimental plan, but the effects of these are not showed in this poster where the results shown are averages of the nitrogen levels.
The experiment at Ødum was established with three repetitions as a split-split-plot experiment with soil tillage as main plot factor, organic matter as sub-plot factor and nitrogen as sub-sub-plot factor.The experiment at Jyndevad was an incomplete split-split-plot experiment with main- and sub-plot factors as at Ødum.
Ploughing for winter crops was carried out in the autumn and for spring sown crops in the spring immediately before seed bed preparation and sowing. Slurry for all crops was given in spring. The coarse sandy soil was irrigated.
In some of the treatments ceramic suction cups of the type 655 x 01 - B1M1 from Soilmoisture Equipment Corp., California were installed at a depth of 80 cm at Jyndevad and 100 cm at Ødum for collection of soil water for nitrate analysis (Hansen 1994).

RESULTS AND DISCUSSION

The coarse sandy soil at Jyndevad

Average yields are shown in table 2. LSD values are not shown because of the incomplete experimental design. The significance is marked by means of s (significant) and n.s. (not significant).

Tabel 2. Yields of grain and potatoes in the crop rotation at Jyndevad 1989-1993. *Hkg grain with 85 pc. DM per hectare. Fresh weight of tubers in hkg per hectare.*

	Potatoe	Winter rye	Spring barley/ rye grass	Spring barley/ fodder rape	Average cereals
Number of years	5	4	5	5	
Green cover crops (*organic matter*)					
0. No cover crops	496[b]	44,4[b]	40,9[a]	41,3[b]	42,0
3. Catch crop and straw	511[a]	45,7[a]	36,5[b]	44,0[a]	41,8
4. Catch crop, straw and slurry	485[c]	40,2[c]	32,0[c]	40,8[b]	37,5
LSD	s	s	s	s	-
Soil tillage					
a. Ploughing 20 cm	507[a]	43,5	37,8[a]	42,8[a]	41,2
b. Ploughing 10 cm	487[b]	43,4	35,1[b]	41,3[b]	39,7
LSD	s	n.s.	s	s	-

\- *not tested*

The yield of potatoe is the total weight of tubers (fresh weight). Catch crops and straw (treatments no. 3) increased the yield of potatoe and winter rye significantly in relation to treatment 0. Application of slurry in treatment no. 4 decreased the yield of potatoe and winter rye significantly, probably because of a considerable evaporation of nitrogen from the slurry.

In spring barley/rye grass, which followed the year after winter rye, there was significant yield decrease for application of organic matter in treatment 3 and 4, probably because of immobilization of nitrogen under the decomposition of a large quantity of rye straw.

In spring barley/fodder rape, which followed the year after spring barley/rye grass, there was a significant yield increase for catch crop and straw (treatment 3) but not for application of slurry (treatment 4). The positive effect in treatment 3 is probably due to the release of nitrogen from the decomposed rye straw and release of nitrogen from the catch crop.

In potatoe as well as in spring barley ploughing to 20 cm gave significantly higher yields than ploughing to 10 cm. The yield of rye was independent of the ploughing depth.

The sandy soil at Ødum

Average yields are shown in table 3. In winter rape and spring barley there were significant positive effects of straw and slurry, whereas winter barley and winter wheat were unaffected by application of straw and slurry. On average of the crop rotations the yield increase with application of straw and slurry was 1.8 hkg grain per hectare (not tested).

All the crops were unaffected by the two ploughing depths.

Table 3. Grain yield in the crop rotation at Ødum 1989-1993.
Hkg grain with 85 pc. DM per hectare. Hkg rape with 91 pc. DM per hectare.

	Winter barley	Winter-rape	Winter-wheat	Spring barley	Crop rotation average
Number of years	4	3	4	4	
<u>Organic matter</u>					
0. No organic matter	49,1	27,3[b]	75,8	43,4[b]	50,3
4. Straw and slurry	49,8	29,5[a]	77,9	45,4[a]	52,1
LSD	n.s.	2,09	n.s.	1,28	-
<u>Soil tillage</u>					
a. Ploughing 20 cm	49,8	28,5	76,4	45,3	51,4
b. Ploughing 10 cm	49,2	28,3	77,5	43,5	51,0
LSD	n.s.	n.s.	n.s.	n.s.	-

- *not tested*

Interactions between years and treatments

The development in yields over the years is shown in figure 1 and 2.

Figure 1 shows the effect of organic matter over the years on the sandy loam at Ødum. In most of the crops a yield decrease with application of organic matter was seen the first 1 to 3 years. During the following years yield increases according to application of organic matter were seen. The interactions between years and organic matter were significant in winter barley and winter rape. However in winter rape only on the 90 % level. Even if the interaction in spring barley and winter wheat was not significant the trends was the same as in the other crops.

Ploughing depths produced no interactions in relation to years and there were no trends in the development over years at any of the experimental sites.

Figure 2 shows the effect of cover crops over the years on the coarse sandy soil at Jyndevad. The interactions were significant in all of the crops.

In potatoe, which followed the year after barley/fodder rape, there was no effect of cover crops the first 1 to 3 years but in 1992 and 1993 there was a positive effect.

In winter rye, which followed the year after potatoe, there were positive effects in 2 of the 4 years.

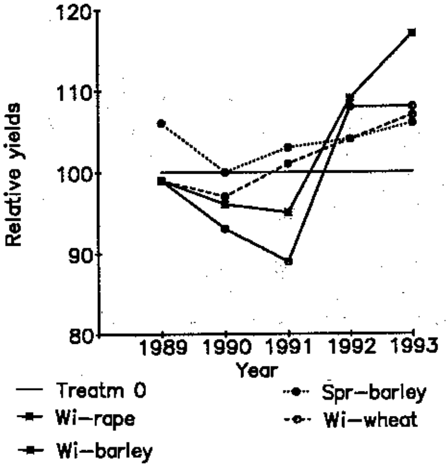

Fig. 1. Interaction between years and organic matter on sandy loam at Ødum. The relative yields of treatment 4 (straw and slurry) in relation to the yields in treatment 0 (no organic matter).

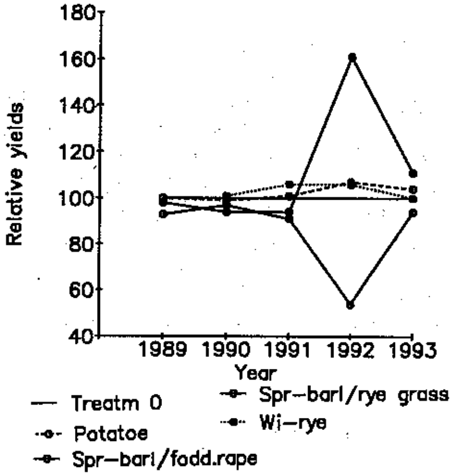

Fig. 2. Interaction between years and cover crops on coarse sand at Jyndevad. The relative yields of treatment 3 (catch crop and straw) in relation to the yields in treatment 0 (no cover crops).

In spring barley/rye grass, which followed the year after rye, there was a negative effect of green cover crops. Especially in 1992 where the peiod May - June was very dry.

In spring barley/fodder rape, which followed the year after spring barley/ rye grass, there were negative effects the first 3 years. In the dry year 1992, but also in 1993, there were positive effects of cover crops and straw. The yield results on the coarse sandy soil showed that yields were very dependent on how much organic matter - especially straw - was added after the preceding crop.

The interaction between ploughing depth and cover crops (not tested) in spring barley/rye grass, which followed the year after winter rye, is shown in figure 3.

It is seen that the excess yield for 10 cm ploughing in treatment 0 (no cover crops) is 5.1 hkg grain per hectare, whereas it is ÷ 10.9 hkg in treatment 3 (catch crop and straw).

The example shows that a ploughing depth of 20 cm is best when a large amount of straw has to be incorporated in the soil.

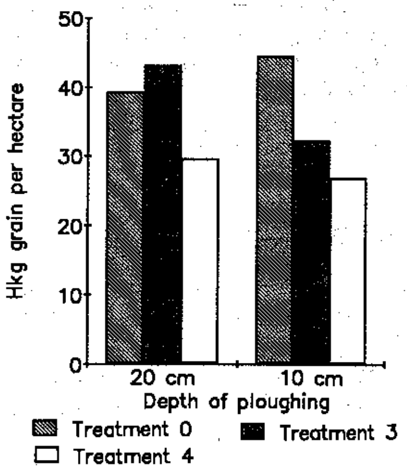

Fig. 3. Interaction (not tested) between ploughing and cover crops in spring barley/rye grass on coarse sandy soil at Jyndevad. Average of 5 years.

NITRATE LEACHING

The addition of a moderate quantity of slurry, incorporation of straw and growing of catch crops in cereal dominated crop rotations reduced the nitrate leaching in relation to omission of slurry, straw and catch crop in the crop rotation. The effect seems first and foremost to be dependent on growth of a catch crop.

Rye grass undersown spring barley was more efficient in reducing nitrate leaching than fodder rape sown after harvest of the barley.

In the period April 1990 - July 1993 nitrate leaching in 3 of the fields at Jyndevad was reduced by 18 - 28 % in treatment 4 (cover crops, straw and slurry) in relation to treatment 0 (no cover crops) at nitrogen application of 80% of the fertilizer recommendations.

CONCLUSION

A ploughing depth of 20 cm gave significantly higher yields than a 10 cm ploughing depth in potatoe and spring barley with catch crops on the coarse sandy soil whereas winter rye was not influenced by the ploughing depth. Especially when large quantities of straw had to be incorporated the 20 cm ploughing depth was the best.

Ploughing depth was without influence on the crop yields on the sandy loam soil.

Catch crops and straw gave significant yield increases in potatoe, winter rye and spring barley with a catch crop of fodder rape on the coarse sand soil whereas spring barley with catch crop of rye grass gave a yield decrease because of immobilization of nitrogen with decomposition of a large quantity of straw in the preceding crop winter rye.

Straw and slurry increased the yield of winter rape and spring barley on the sandy loam soil but in winter barley and winter wheat only trends were seen.

Application of organic matter gave yield decreases the first 1 to 3 years, but afterwards yield increases were measured in most crops - especially on sandy loam soil.

Catch crop, straw and slurry reduced nitrate leaching in relation to omitting these factors. Undersown rye grass catch crop gave less nitrate leaching than autumn sown fodder rape catch crop.

Results of yields as well as nitrogen leaching have shown that the experiments should be continued for several years.

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EFFECTS OF DIFFERENT TILLAGE SYSTEMS ON MAIZE YIELD ON CHERNOZEM TYPE OF SOIL

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ABSTRACT

The long term field experiment was set up in Zemun Polje on chernozem type of soil. The following factors were investigated: tillage (no tillage, reduced tillage and conventional tillage), fertilizing (without fertilizers, with 330 kg/ha and with 660 kg/ha of NPK fertilizers) and irrigation (with and without irrigation).

During the period 1988-1993, the highest yield was obtained with conventional tillage (9.47 t/ha), higher by 17.6% than yield obtained without tillage. When no fertilizers were used, the yield was lower by 0.39 t/ha (4.70%) than yield when 330 kg/ha of NPK were applied. The 6-year average yield obtained under irrigation was 2.89 t/ha (38.60%) higher than yield attained when no irrigation was used.

INTRODUCTION

Reduced tillage has not been widely spread in Yugoslavia. The aim of our study was to investigate the applicability of reduced and no-tillage practices on chernozem type of soil. Shortage of fuel during the last ten years confirmed the importance of such research.

MATERIALS AND METHODS

Long term field experiment was established on chernozem type of soil in Zemun Polje. During a period 1988-1993, maize (Zea mays) was grown in rotation with winter wheat. The maize hybrid ZP-704 was used in experiment.

The following factors were investigated: tillage (no tillage, reduced tillage and conventional tillage), fertilizing (without fertilizers, with 330 kg/ha and with 660 kg/ha of NPK fertilizers) and irrigation (with and without irrigation). Each treatment was replicated four times in split-split-plot design, using plots of 28 m^2 size.

In no tillage plots, maize was planted in spring, directly into the wheat stubble. In reduced tillage plots, soil was cultivated with rotary tiller 15 cm deep and maize was planted in spring. Conventional tillage plots received shallow plowing of stubble (15 cm deep) after wheat harvest, deep plowing (25 cm) in autumn, seedbed preparation with seedbed conditioner and planting. In each plot planting was performed with John Deere Max Emerge II planter.

Weeds were controlled with combination of 4 kg/ha of Metalachlore (Dual 500-EC) and 2 kg/ha of Prometrine.

The following quantities of water were used in irrigated plots: 377.4 mm in 1988 (sum from 4 irrigations), 177.7 mm in 1989 (applied in one irrigation), 355.2 mm in 1990 (sum from 5 irrigations), 266.4 mm in 1991 (sum from 3 irrigations), 255.0 mm in 1992 (sum from 6 irrigations) and 337.5 mm in 1993 (sum from 9 irrigations).

The moisture content of the soil was determined gravimetrically on an oven dry basis for depths of 0-10, 10-20, 20-30 and 30-40 cm.

Yields were determined based on samples from two center rows of each plot. Analysis of variance (a model for split-split-plot design) was used for statistical analysis. The least significant difference test (LSD) was used to determine the significance of treatment effects. All statistical analysis was performed using MSTAT statistical package.

Basic meteorological data for this location are presented in Table 1.

Table 1 Total annual precipitation (mm) and mean annual temperatures (^{o}C) at experimental site from 1988 to 1993

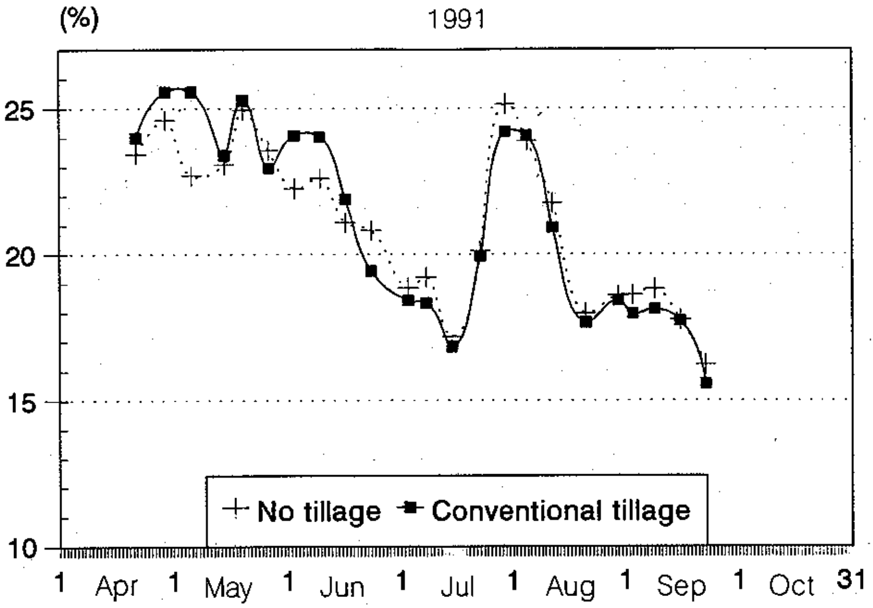
Period	1988	1989	1990	1991	1992	1993	1953-1984
Precipitation							
I-XII	499.7	558.9	438.7	713.5	445.9	446.4	602.9
IV-IX	246.8	392.6	228.0	381.3	236.6	207.7	345.8
HID*	570.8	527.6	399.6	655.1	495.1	463.6	-
Temperatures							
I-XII	11.6	11.8	12.3	11.1	13.0	12.2	11.1
IV-IX	18.6	18.0	18.2	18.0	20.6	20.3	17.7

HID* Total precipitation: Octoberof the previous through September of the current year

RESULTS AND DISCUSSION

The influence of tillage practice on soil water content in arable farming system can be clearly seen on Fig. 1. Two years were compared: 1993 as a dry one and 1991 as a year with sufficient precipitation. In both years, soil water content was higher in CT-plots until 2nd decade of June. After that period, it was higher in NT-plots for a couple of percents almost until the harvest. Higher water content in the April-Jun period can be attributed to better water infiltration capabilities of cultivated over non-cultivated soil. The evaporation rate is also higher, resulting in poorer water holding capacity.

In 1991, soil water content curve followed the similar pattern in both irrigated and non-irrigated plots, although it was higher in irrigated. In 1993, it tends to oscillate about certain value in irrigated plots, while decrease in time in non-irrigated plots till the end of August. The situation is almost the same in all three tillage systems, although it was a little bit more advantageous in NT over CT-plots.



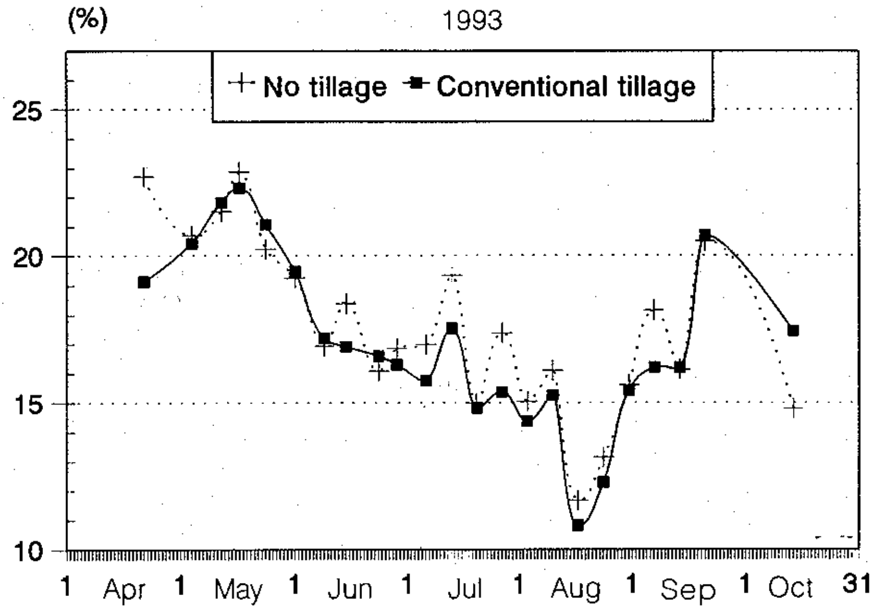


Figure 1 Effect of tillage on soil moisture content under dry farming

In this experiment, effects of tillage on maize yield were proven to be significant during 1988-1993 (Tab. 2). The-six year average yield was the highest in conventional tillage (CT) and the lowest in no tillage (NT). CT gave higher yields than NT and reduced tillage (RT) in four out of six years. The similar results were also reported by Hughes et al. (3). In the extremely dry 1993, with only 207.7 mm of precipitation during April-September, NT gave higher yield than RT. Although higher, it was not significantly different. In 1991, with sufficient precipitation, the highest yield was obtained under CT and the lowest under NT. Also, differences are significant on all three tillage plots (Videnovic et al. 2, 3).

The 6-year average maize yield depend on the amount of fertilizers. The highest amount of fertilizers resulted in the highest yield. Comparing to not fertilized plots it averaged 12%, ranging from 0.5% in 1989 to 55% in 1988.

With the exception of 1991, irrigation significantly increased yield in all six years. The increase averaged 38.6%, ranging from 1% in 1991 to 69% in 1992.

Table 2 Effects of tillage practice, fertilizing and irrigation on maize yield (t/ha)

	1988	1989	1990	1991	1992	1993	Average t/ha	Average %
				Tillage practice (T)				
NT	7.32	6.23^{b}	8.36^{b}	7.57	8.58^{b}	10.26 a	8.05	100.0
RT	9.58	6.84^{a}	9.47^{b}	9.93	10.41 a	9.49^{a}	9.29	115.4
CT	9.28	7.05^{a}	10.67 a	10.85	10.64 a	8.33^{b}	9.47	117.6
LSD	0.91	0.49	1.16	0.67	0.55	1.07	-	-
				Fertilizing (F)				
0	7.32	6.61	8.99^{b}	8.49^{b}	9.46^{b}	8.64^{b}	8.25	100.0
330	7.55	6.87	8.39^{b}	9.19^{b}	9.88^{a} b	9.94^{a}	8.64	104.7
660	11.32	6.64	11.11 a	10.67 a	10.29 a	9.49^{a} b	9.92	120.2
LSD	0.91	ns	0.97	1.00	0.59	0.89	-	-
				Irrigation (I)				
I	7.21	6.27	7.74	9.40	7.34	6.98	7.49	100.0
I	10.24	7.15	11.26	9.50	12.41	11.74	10.3 8	138.6
LSD	s	s	s	ns	s	s	-	-
				LSD for interactions				
TxF	1.58	ns	ns	1.74	1.03	1.55	-	-
TxI	ns	0.70	ns	ns	0.78	ns	-	-
IxF	ns	ns	1.37	ns	0.84	1.26	-	-
TxIxF	ns	ns	ns	ns	1.45	ns	-	-

In each column, the values are significantly different when not followed by the same superscript (the least significant difference was used to determine significance, P=0.01).
s: signifficant; ns: not signifficant

CONCLUSIONS

According to six-year average data, it can be concluded that tillage, fertilizing and irrigation significantly influence maize yield. Their interactions however, are not allways signifficant.

The highest maize yield was attained under conventional tillage (9.47 t/ha), by 17.6% higher than under no tillage. Yield difference between conventional and reduced tillage is only 0.18 t/ha (2.2%). It indicates that reduced tillage can be implemented without signifficant yield reductions.

Maize yield responded significantly to high doses of NPK fertilizers. Comparing to yield attained without fertilizers, 330 kg/ha of NPK fertilizers increased yield by 0.39 t/ha (4.7%) and 660 kg/ha increased it by 1.67 t/ha (20.2%).

The average yield increase under irrigation was 2.89 t/ha (38.6%). Increase was recorded even in the year with sufficient precipitation, alhough it was not signifficant.

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STUDY OF MAIZE PRODUCTION APPLYING ALTERNATIVE TILLAGE SYSTEMS IN THE PROVINCE OF VOJVODINA

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ABSTRACT

The system of conservation tillage brought to higher content of water in soil but it had no effect on crop yield. The assumptions that new tillage systems will bring to same or even higher yields in first year of the investigation were not realized. In four-year period, highest yields were achieved with conventional tillage. Compared with conventional, conservation tillage (chisel) decreased the yield for 6% and no-tillage for 16%. However, the investigation of these as well as some other alternative tillage systems for maize production should be continued further on.

Key words: Maize (Z. mays L.), tillage systems, alternative systems, conservation tillage, conventional tillage, chisel.

INTRODUCTION

In Yugoslavia, the investigations of alternative tillage systems bave been initiated a long time ago (Drezgić, 1968, Kosovac, 1967).

These investigations have been continued further on, but what is more important, new tillage systems have been accepted in large scale production.

In Vojvodina, reduced tillage system is dominant in wheat production (over 80% of areas are included).

The investigations of the possibility of zero ploughing production of maize, sunflower and soybean are rare and had no practical application.

The trials of Kosovac (1967) and Konstantinović (1980) showed that reduced tillage in maize production can give yields comparable to yields from conventional tillage. Similar results were achieved by Triplett (1968) and Jones (1968). Zumbach achieved maize yield higher even for 38%.

In our country, direct drilling brought to lower yields because of unfavourable stand density, since we had no special driller (Konstantinović, 1980, Videnović 1982, Žugec, 1986).

Low temperatures do not represent a limiting factor for maize development (Farazdaghi et al. 1985, Sadler et al. 1985).

METHOD AND AIM OF THE INVESTIGATION

Weather and soil conditions

The trails were established at three different locations: Kać, Mikićevo (Subotica) and Titel which are three different regions with respect to agroecology, soil types and climate.

All trials which lasted for 5 years (1987-1991), were established according to the method of Zade - long plots in four replications The following crop rotation design was applied: sunflower, wheat, soybean, maize, with some variation.

The tillage systems studied were: 1. conventional tillage, ploughing at 25 cm (control), 2. Conservation chisel tillage, 25 cm and 3. Direct drilling, zero tillage in autumn and spring. A special driller Hiniker with two sets of disks was used for sowing. The disks placed on strong spring are horizontal for cleaning of harvest residues and vertical for cutting furrow.

The studied parameters were: soil compaction and soil moisture, weed flora, and yield, as the most important parameter.

The yield results were processed according to acknowledged statistical methods and are presented in tables.

In the initial year of the study (1988) May was cold and humid and sprouting was delayed. Average rainfall was registered for June, while July and August were dry and hot.

In the second year (1989) the weather conditions were similar as in the previous year.

Even the third year had unfavourable weather conditions for maize development. Extreme drought occurred in the period of seed filling.

The fourth year (1991), with sufficient rainfall in July and August was more favourable for maize development.

In Kać, the trial was established on a chernozemlike meadow soil type which has average content of humus and Ca. In Mikićevo, the trial was established on a chernozem soil with shallow accumulative horizon (app. 30 cm) and high content of sand. In Titel, the trial was established on humogley, a heavy hydromorphic soil. Besides these unfavourable conditions, the location has not regulated water scheduling and frequent excess wetness in spring, even to the middle of summer. Consequently, the experiments failed in the first and fourth year.

RESULTS

All tillage system variants were applied in autumn applying 350 kg/ha of fertilizer (15:15:15). On the variant with direct sowing, the harvest residues were chipped and fertilizer spread.

The sowing of the maize hybrid NSSC-444 was performed on April 21. The plant density was 57,000 plants/ha. This density was applied at all variants except on the variant with direct sowing, where it was 44,200 plants/ha, non-uniform, although the special driller Hiniker was used. No difference between the control plot and chisel tillage system was registered. However, the maize plants developed slowly and their color was light at the variants with direct sowing. Appropriate herbicides were applied for the crop protection. No problems occurred in the course of growing period.

Soil moisture was measured in the course of maize growing in three periods which are important for maize development. Table 1 presents the results which indicate that the soil moisture in conservation system was higher from 5.72 to 11.93% than in the conventional. In the first period, the differences were low, while in the third, the soil sampled from the system of direct sowing had 20.4% higher moisture than that from the conventional. This results is higher than the results achieved by other authors. However, higher water content on the variant with direct sowing did not increase the yield, but the yield on this variant was even the lowest.

Tab. 1 Soil moisture in Kać, 1988 (Glušac D.)

Tillage system	Soil moisture % 0 - 60 cm						Aver.	Index
	May 6,88	Index %	June 5,88	Index %	June 30	Index %		
Convent. till.	19.91	100.00	19.56	100.00	12.44	100.00	17.30	100.00
Conservat. till.	20.20	101.45	21.79	111.40	12.88	103.54	18.29	105.72
No tillage	22.15	111.25	22.00	112.47	14.98	120.42	19.71	113.93

Table 2 presents the results of maize yield achieved in Kać (1988). Contrary to our expectations that the conservation system will give higher maize yields, at least in the first year, the yields were lower with direct sowing for 33%, with chisel for 19%. The differences occurred to be highly significant.

Lower yield achieved with direct sowing can he explained by unfavourable stand density which was lower for 22.5%. However, on the variant where chisel tillage system was applied, the stand density was as on the variant where conventional tillage system was applied. The extended effect of previous tillage all other factor which is out of our control was missing.

The year 1988 was unfavourable for maize growing in Vojvodina. The average yield was 4,610 kg/ha, in some regions even 1,500 kg/ha.

Tab. 2 Maize yields in Kać, 1988

Tillage systems	Replications				Average	Index
	I	II	III	IV		
Conventional tillage	6.377	6.511	6.473	6.490	6.462	100
Conservat. tillage	5.308	5.105	5.285	5.212	5.227	81
No tillage	4.290	4.410	4.350	4.360	4.352	67
LSD	0.05 0.01	140 213			Average	5.347

Table 3 presents the yields of maize achieved at the location of Mikićevo where the yield was lower for 1,669 kg/ha on average than in Kać. This difference is large and connected with weather conditions in the region of North Bačka. The yield of maize was extremely low in the whole region. However, the yield achieved on our plot, although low, was two times higher than the average. The comparison of the tillage systems showed the similarity with those in Kać, although the differences are less expressed. Compared with the alternative tillage systems, the conventional system gave maize yield higher for 4 and 10%, respectively. The differences are highly significant.

The differences in replications are low and LSD values are low as well.

Tab. 3 Maize yields in Mikićevo, 1988

Tillage systems	Replications				Average	Index
	I	II	III	IV		
Conventional tillage	3.956	3.734	3.895	3.898	3.870	100
Conservat. tillage	3.688	3.720	3.680	3.697	3.696	96
No tillage	3.502	3.395	3.482	3.490	3.467	90
LSD	0.05 0.01	97 146			Average	3.678

Table 4 presents the soil water conductivity. The differences between different tillage systems were low with respect to this parameter. A contradiction is evident with respect to this parameter: considering the soil moisture, the soil tillage systems have different values from those for yield.

The highest content of water was found in the variant with direct sowing (3.94% higher) but it had the lowest yield. The highest yield was achieved in the variant with conventional tillage, in which lower soil moisture was registered.

Tab. 4 Soil moisture in Mikićevo (Glušac)

Tillage systems	June 13, 88	June 27	Aug.30	Average	Index
	I	II	III		
Conventional tillage	9.60	17.20	11.21	12.67	100.00
Conservation tillage	9.49	17.55	11.44	12.87	101.18
No tillage	10.91	17.16	11.46	13.17	103.94

In 1989, the trial with maize was established after wheat in Kać. This year had very unfavourable weather conditions for maize development as well. In the regions of North Bačka and North Banat, the drought was so strong that it was qualified as elemental catastrophe. The average yield in Vojvodina was 4,480 kg/ha, which was lower than the yield in 1988. However, the drought did not occur in some regions of Vojvodina: Srem, South Banat and Podunavlje.

This year was characteristic according to severe winter, and a spell of drought in summer. Dry and cold May affected the slow maize development. During summer, not only dry July and August, but viruses and other diseases occurred as well. The average yield achieved in our trial was 5,598 kg/ha (Table 5) which was higher than the average yields achieved on farms (4,200 kg/ha). Considering the variants of tillage, this year was more favourable for the conservation tillage system. The difference between the chisel tillage, in which the achieved yield was 5,868 kg/ha, and the conventional tillage was minor (1%)..

The yield from direct sowing was lower for 13%. This difference is significant at the level of 0.05%.

Tab. 5 Maize yields in Kać, 1989

Tillage systems	Replications				Average	Index
	I	II	III	IV		
Conventional tillage	5.977	5.648	6.320	5.380	5.831	100
Conservat. tillage	6.250	5.540	5.750	5.930	5.868	101
No tillage	4.880	5.100	5.330	5.068	5.094	87
LSD	0.05 0.01	534 809			Average	5.598

Considering the soil moisture (Table 6, average for 3 periods), the sequence of yields according to variants agreed with the sequence of soil moisture. The highest soil moisture was registered in variant with chisel tillage (20.50%) where the highest yield was achieved as well (5,868 kg/ha). The lowest soil moisture was registered in variant with direct sowing (17.84%), which was lower than in control for 9%. Here, the yield was also lower for 13%.

Tab. 6 Soil moisture in Kać (Glušac, D.)

Depth in cm	Conventional tillage	Conservation tillage	No tillage
0 - 10	15.61	18.61	15.87
10 - 20	20.97	21.43	17.52
20 - 40	20.92	21.72	19.06
40 - 60	20.93	20.36	19.22
> 60	19.16	20.36	17.51
Average	19.52	20.50	17.84

In the third year of the investigation, the plot was established in Kać, where the preceding crop was soybean. This year had also unfavourable weather conditions for maize growing. The yield of maize achieved on state and private farms was only 3,540 kg/ha and 3,000 kg/ha, respectively. This is only 50% of the yields achieved in 1979-84, which were higher than 6 t/ha.

Under such conditions, the average yield achieved in our plot was 2,517 kg/ha (Table 7), which was lower than the yield achieved on a farm (3,890 kg/ha). Considering the tillage variants, 11-21% lower yields were achieved where alternative systems were applied. That year, the yield from chisel variant was lower than the yield in the system of direct sowing.

Tab. 7 Maize yield in Kać, 1990

Tillage systems	Replications				Average	Index
	I	II	III	IV		
Conventional tillage	2.977	2.454	2.960	2.890	2.820	100
Conservation tillage	1.980	2.520	2.222	2.200	2.230	79
No tillage	2.610	2.360	2.538	2.490	2.500	89
LSD	0.05 0.01	410 809			Average	2.517

In that year, the tendency of water content and yield (Table 8) was opposite. The lowest soil moisture was found on the variant with conventional tillage (15.64%) which had the highest yield which is lower than the variant with chisel tillage for 21.73%, which was not found by other researchers.

In the fourth year of the investigation (1991), the highest yield of 6.8 t/ha was achieved (Table 9). This yield is higher than average yield achieved on a farm (5.7 t/ha). After three succeeding unfavourable years, this year had the most favourable weather conditions for maize growing when the average yield in state farms was 7.9 t/ha.

Considering the variants, the highest yield of 7,293 kg/ha was achieved in conservation tillage system, i.e. chisel tillage which is 5% higher than with conventional tillage. The variant with direct sowing was behind the control for 9%. However, the yield achieved in this variant was 6,332 kg/ha, which can be considered a high yield, since it was achieved in Subotica, on poor soil, on a stationary plot.

Tab. 8 Soil moisture (Glušac, D.)

Depth in cm	Conventional tillage	Conservation tillage	No tillage
0 - 10	13.56	16.62	15.52
10 - 20	15.29	19.19	18.97
20 - 40	15.01	20.42	20.52
40 - 60	19.07	24.84	22.54
> 60	15.30	18.15	18.67
Average Index	15.64 100.00	19.04 121.73	19.24 123.18

Tab. 9 Maize yield in Mikićevo 1991

Tillage systems	Replications				Average	Index
	I	II	III	IV		
Conventional tillage	6.850	6.805	7.273	6.943	6.967	100
Conservation tillage	7.005	7.563	7.094	7.511	7.293	105
No tillage	6.269	6.425	6.225	6.405	6.332	91
LSD	0.05 0.01	384 583			Average	6.964

Table 10 presents the sum of the results according to location and year (5 plots, 4 years). It is evident that the average yield of four-year period was 4,800 kg/ha, which should be considered as a high yield since out of four years, three years were affected by severe drought.

Considering the tillage variants, the conventional tillage gave the highest yield of 5,190 kg/ha, followed by chisel tillage where the yield was lower for 6% and finally, direct sowing where the yield was lower for 16%. There was no significant difference between the control and chisel tillage. The chisel tillage showed to be best in Kać in 1989 and in Mikićevo in 1991. However, the yield on this variant was lowest in Kać in 1990.

The variant with direct sowing is risky because of the yield of 4,349 kg/ha, which was 16% lower than the yield achieved in the control (four-year average). However, the analysis of the yields according to years showed that the only risk existed in the first year of the study in Kać when direct sowing gave yield lower 37%, while in other years the yield decrease was acceptable since it ranged from 9 to 13%. Consequently, we think that in our conditions, direct sowing can give higher yields than achieved in our study. The yields of direct sowing were comparable to yield from conventional tillage or somewhat lower, as it is stated in foreign literature. The low yield of maize achieved with direct sowing can be explained also by inadequately equipped driller Hiniker and plant stand density.

Tab. 10 Maize yields in the experiment 1988-91 (kg/ha)

Tillage systems	Years - Locations					Average	Index
	1988 Kać	1988 Mikićevo	1989 Kać	1990 Kać	1991 Mikićevo		
Convent. tillage	6.462	3.870	5.831	2.820	6.967	5.190	100
Conservat. till.	5.227	3.969	5.868	2.230	7.293	4.862	94
No tillage	4.352	3.467	5.094	2.500	6.332	4.349	84

The Vojvodina Province is the region of extensively developed agricultural production and reduced tillage systems (direct sowing) have no prospect.

However, Vojvodina is arid area having extreme spell of drought in July and August and therefore the systems of conservation tillage are prospective, especially the system of chisel tillage, then reduced tillage by discing.

Conclusion

The possibility for growing maize according to alternative tillage systems in Vojvodina was achieved only partially.

The highest yield was achieved in conventional tillage system with ploughing in autumn and seed bed preparation in spring.

The system of conservation tillage based on chisel tillage in autumn and seed bed preparation in spring, gave the yield which was 6% lower than with conventional tillage. This system of soil tillage for maize growing deserves to be further studied and improved.

Direct tillage without autumn and spring tillage gave the lowest yield. This yield was 16% lower, but in the first year of the study it was lower even for 33% due to unfavourable stand density, which represents the risk for the production.

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SIMPLIFIED TILLAGE IN MAIZE MONOCULTURE

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ABSTRACT

Effect of simplified tillage and mulching on grain yields of maize cropped continously and on some soil chemical properties was studied in the years 1989-1993 on two types of soil. Under 2-4 years of maize monoculture, conventional tillage significantly increased grain yields when compared to simplified tillage (disking only) and to 0-tillage (direct seeding). Application of straw mulch had no significant efffect on grain yields but was advantageous in offsetting the decline of humus content of the soil.

INTRODUCTION

Maize can be successfuly grown under monoculture even though some research data indicate that there is a yield reduction following 3-4 years of such a cropping system (Griffith et al., 1988, Machul, 1993). Reported data provide grounds to believe that maize does not respond with a significant yield reduction to tillage simplifications such as shallow cultivation or even leaving the soil untilled (Shear, Moschler, 1969). There is no agreement on the advisability of applying chopped maize straw to inter-row spaces. The treatment may be beneficial by restricting water losses from the soil (Trippler et al., 1968), or harmful by keeping the sun heat off the topsoil (Gupta et al., 1983). Mulching with maize straw can also lead to increased incidence of pests and diseases (Vez, 1974).
Investigations in this area carried out in Poland failed to provide unambiguous data concerning low input systems of maize cultivation. In this connection, an attempt was made to evaluate the effect of three systems of seedbed preparation for maize including mulch application on grain yields and soil chemical properties.

MATERIAL AND METHODS

Field experiments were conducted in 1989-1993 on two soil: a brown soil developed from loess (Werbkowice) and a medium heavy alluvial soil (Puławy). Throughout the experiment the same three tillage systems were apllied: conventional (winter ploughing and springtime seedbed preparation), simplified (preplant disking only), 0-tillage involving direct seeding (Roundup was used to kill the weeds). Another experiments factor was application of chopped maize straw vs. no mulching (maize straw was gathered from the field).
Annual mineral fertilization included N-120, P_2O_5-90, K_2O-140

kg/ha. The experiment was cropped to an early hybrid KLG 2210 seeded at 100,000 grains per 1 ha. Immediately after seeding the seedbed was sprayed with Gesaprim 50/Dual 720 EC herbicide mixture at 2+2 kg/ha. Grain yields and harvest index of maize were determined. Yield components were evaluated on 10 ears collected from 10 successive plants in a row. Soil samples were extracted each year after maize harvest. Routine methods were used in chemical analysis.

RESULTS AND DISCUSSION

Data shown in Tab. 1 indicate that maize grown under monoculture in the 2end, 3rd, and 4th year yielded significantly more grain when tilled conventionally as compared to simplified tillage and 0-tillage. Failure to plow the seedbed results in reduction of maize grain yields as shown earlier in research conducted elsewhere (Kaspar et al., 1987, Griffith et al., 1988).

Tillage treatments had no major effect on harvest index. The effect of tillage treatments studied was similar at both sites. Mulching had no signifiacant effect on grain yields. An exceptionally low yield in 1992 was attributable to precocious ripening caused by hot and dry weather in July and August.

The tillage treatments had a minor influence on plant density, 1000-grain weight, grain number per ear and grain weight per ear. The number of ears on unit area was the most important yield-forming factor. Maize cultivated conventionally yielded, on average, 6,000-8,000 ears more than that from treatments involving reduced tillage and 0-tillage.

Moisture content of maize grain at harvest from conventional tillage was 1% lower than from 0-tillage which agrees well with an earlier report by Griffith et al., 1988. Mulching can also increase moisture content of grain (Swan et al., 1987). However, no such effect was observed in this study.

Reduced tillage or, to even a larger extent, no tillage at all increased infestation with perennial weeds (Cirsium arvense, Agropyron repens, Convulvulus arvensis). The finding is supported by other reports (Blevins et al., 1983).

Following five years of maize monoculture there was a fall in soil pH at 0-30 cm depth. The pH of the soil that received conventional tillage changed from 5.6 to 5.2, the pH of the untilled soil decreased from 5.6-5.0. It as accompanied by a slight decrease in soil humus content, regardless of tillage treatment (from 1.88 to 1.67%). Mulching was effective in offsetting the decline in humus content of the soil.

Analysis of the content of some nutrients at 0-30 cm soil depth showed potassium and magnesium contents to remain unaltered following 4 years of monoculture, regardless of tillage treatment. However, the phosphorus content was slightly higher in the untilled soil - a finding similar to those reported by Shear and Moschler, 1969 and by Blevins et al., 1988.

Table 1 Effect of pre-sowing soil cultivation on grain yields of maize (t/ha) Average of 2 experiments. Not significant: n.s.

Years of maize monoculture	Tillage treatments			LSD .95
	conventional	simplified	0-tillage	
1	9.36	9.68	8.98	n.s.
2	7.90	6.75	6.73	0.641
3	8.43	7.83	7.27	0.599
4	5.46	4.58	4.56	0.555
5	7.05	6.99	7.09	n.s.
means	7.64	7.17	6.92	0.321

CONCLUSIONS

Under 2-4 years of maize monoculture conventional tillage significantly increased grain yields when compared to simplified tillage (disking only) and 0-tillage (direct seeding). The difference was related to the number of ears per ha higher by 6,000-8,000 in the conventional tillage treatment. Mulching failed to affect beneficial in preventing the decline of soil humus content. An increased infestation with perrenial weeds was the result of 0-tillage.

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THE MAIN SOIL TILLAGE FOR GRAIN CROPS IN THE NORTHERN KAZAKHSTAN

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ABSTRACT

In dry conditions of the Northern Kazakhstan soil conservation tillage including the autumn loosening of fallow and stubble land to 25-27 cm in combination with the accumulation of snow to the depth of 35-40 cm gives the better spring field moistening and increase in spring wheat yield by 0.2-0.6 t/ha(15-30%) in not less than 50% of years as compared with plowing to the same depth and shallow sweep tillage to 12-14 cm.

When testing the sweep-type implements on the main autumn soil tillage it was found out that the tillage depth but not the type of used implement was of primary importance in obtaining effect. The optimaldepth of autumn sweep tillage for water intake of 35-40 cm snow cover is 25-27 cm.

INTRODUCTION

The main objective of soil tillage system in dry steppe regions is the creation of maximum moisture accumulation, the rational utilization of soil moisture,the optimization of phytosanitary field conditions and soil nutritive regime.The use of moldboard plowing proposed by V.R.Williams in the end of 30-s had positive results not everywhere.The frequent droughts and intensive development of wind-erosion processes in the Northern Kazakhstan demanded the necessity of searching for new technological solutions in the steppe farming practices.

In 50-s T.S.Maltsev proposed the method of nonmoldboard soil tillage in which disk equipment and moldboardless plows were used instead of plows (Zayev,1965;Maltsev,1971).The works of A.I. Barayev(1975) and A.N.Kashtanov(1988) made the basis for the development of soil conservation farming practice that is now widely used in the steppe regions with a high potential of water and wind erosion.

Side by side with the further improvement of soil conservation farming practice some scientists assume the need of moldboard plowing once in a rotation.The main argument of this is the heavy differentiation of arable layer by its fertility with long-term use of subsurface tillage.

The aim of our study was to comparably evaluate the methods and the depth of main soil tillage on fallow and stubble land as applied to the use of traditional and new soil tillage implements taking into accounts the natural conditions of the Northern Kazakhstan

MATERIALS AND METHODS

The landscape of the Northern Kazakhstan is a weakly rolling plain and small mountains occur only in its southern part.

Agroclimate conditions are not uniform and are characterized by three natural zones:forest-steppe,steppe and semi-desert.The soil cover of the main grain production area is presented by chernozem and chestnut soils.

The climate of the region is characterized by the sharp continentality manifested by the great range of air temperatures and small amount of precipitation.The average yearly temperature is about +1.3°C,the temperature in January is -16 -19°,in July +18-20°,annual precipitation is 300-350 mm.

The long-term studies of soil tillage methods were carried out on southern calcareous loamy clay chernozem with humus content 3.5 -4%,P_2O_5 - 1.5-2.2 mg/100g of soil,N-NO_3 - 1.0-1.9 mg/100 g of soil.The field experiments included the following soil treatments: 1)plowing to 25-27 cm by plow with skimmer;2)deep subtillage with a sweep to 25-27 cm;3)shallow subtillage with a blade to 12-14cm; 4)tillage at different depth (the alternation of deep and shallow subsurface tillage).

RESULTS AND DISCUSSION

The influence of different soil treatments on soil density in the layer 0-30 cm was not significant. The increased compactness was recorded only in the layer 20-30 cm after shallow subsurface tillage (Table 1).

Table 1.The influence of autumn soil tillage treatments on the bulk density and the spring available water storage in the layer 0-100 cm (average for 1980-1992)

Soil treatment	Bulk density,g/cm³ layer,cm 0-10	10-20	20-30	Water storage,mm on fallow	on stubble
Deep subtillage to 25-27 cm	0.95	1.20	1.01	121.7± 5	113±7
Plowing to 25-27 cm	0.91	1.02	1.10	111.9± 7	101±9
Shallow subtillage to 12-14 cm	0.97	1.04	1.21	116.7± 5	103.8±6
Tillage at different depth	o.92	1.00	1.12	-	106.3±5

The available water storage in soil treatments ranged widely during studies.The greatest variability by years was observed on stubble in the variants with plowing and shallow subsurface tillage that was caused by the smaller snow accumulation in the first case and by poorer conditions of melting water intake in the second one.

Because of higher cloddiness of topsoil and stubble conservation on nonfallow background the subsurface tillage treatments were in highly wind-resistant condition (erodibility not more than 20 g/5 min) and after plowing - moderately wind-resistant (erodibility 80-120 g/5 min).

The content of labile phosphorus forms in arable soil layer according to treatments differed little.In the plowing treatment the increased nitrate content was recorded in most cases but it didn't exceed the value of high availability.

The amount of annual weeds was the lowest after plowing and of perennial ones after shallow subsurface tillage. The perennial offset weeds,mainly bindweed (Convolvulus arvensis L.), had the largest biomass after plowing.

The grain yield depended to a certain extent on the soil tillage treatment (Table 2).

Table 2.The yield of spring wheat as effected by the soil tillage treatment (average for 1980-1992)

Soil treatment	On fallow		On stubble	
	yield, t/ha	coefficient of variation,%	yield, t/ha	coefficient of variation%
Deep subsurface tillage to 25-27 cm	1.93	32.7	1.57	32.6
Plowing to 25-27 cm	1.86	32.9	1.48	50.0
Shallow subsurface tillage to 12-14 cm	1.69	32.1	1.25	39.0
Tillage at different depth	-	-	1.40	32.7

In average the highest yield and the least variation of yield's values by years were recorded after fallow subsoiling to 25-27 cm,where the yield gains were in the range of 0,2-0,6 t/ha as compared to other treatments.

The influence of tillage method becomes apparent more contrasting after nonfallow background that is mainly associated with the conditions of winter precipitation accumulation and melting water absorption.On the grain stubble the stabilizing effect of subsoiling is demonstrated to a greater extent as compared to other treatments that is evidenced by the yield variation in years.

The probability analysis of the spring wheat yield change depending on soil tillage method by years is given in Table 3.

Table 3. The probability analysis of the dependence of spring wheat yield on the tillage treatments

Probability,%	Probability situation	Level of yield gain,t/ha
	On fallow	
54	Deep subsurface tillage had an advantage over shallow one	0.2-0.6
38	Plowing had an advantage over shallow subsurface tillage	0.2-0.4
23	Deep subsurface tillage had an advantage over plowing	0.2-0.4
23	No significant differences	-
8	Plowing had an advantage over deep subsurface tillage	0.26
	On stubble	
67	Deep subsurface tillage had an advantage over shallow one	0.15-0.5
50	Deep subsurface tillage had an advantage over plowing	0.15-0.8
50	Plowing had an advantage over shallow subsurface tillage	0.4-0.8
17	Plowing was inferior to shallow subsurface tillage	0.3-0.5
8	Plowing had an advantage over deep subsurface tillage	0.2
8	No significant differences	-

The analysis of yield data shows that the efficiency of the soil tillage methods depends on weather conditions to a great extent. In very dry years with low summer rainfall rate when autumn-winter precipitation has the determinant influence on yield formation, the deep autumn subtillage has an advantage because the conditions of snow accumulation are more favourable than after plowing, and melting water absorption is better than after shallow subsurface tillage.

CONCLUSION

The soil conservation main tillage including the deep loosening of fallow or grain forecrop at the depth of 25-27 cm provides for increase in spring wheat grain yield at the level of 0.2-0.6 t/ha in not less than 50% of cases as compared to plowing and shallow subsurface tillage,that points to relatively high stabilizing effect of this practice on the level of grain production.

In the technological part of the main soil tillage the leading factor is the depth of tillage and the type of tillage implement has the subordinate character.

In extremely dry years with low amount of summer precipitation, when the grain yield is formed mainly by autumn-winter precipitation,the deep autumn loosening of soil to 25-27 cm has an advantage over plowing to the same depth and against shallow subsurface tillage.

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MINIMUM TILLAGE FOR POTATOES

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ABSTRACT

Yields and quality of potato haulm and tubers were measured at three dates of harvesting during the years 1987 to 1993 in a long-term tillage trial established in 1980. Planting in untilled, straw-free soil was compared with planting in conventionally tilled soil with autumn ploughing. Direct planting resulted in delayed emergence and plant development, but also in later haulm senescence, so that the length of the growing period was increased. Tuber yields harvested in late August were greatest with conventional tillage, but with harvesting after 10 September direct planting gave the highest yields. No difference in tuber quality or shape were observed between tillage treatment at any time. Haulm quality and greenness were greatest with the latter treatment, and the nitrogen consentration of both haulm and tuber was highest under this tillage system.

A trial was performed in 1992 with direct planting in the presence of chopped straw, following a single pass by a horisontal rotary harrow. The trial site had not been ploughed since 1977. Yield and tuber quality in 1992 and 1993 were the same as on a conventionally tilled reference area.

INTRODUCTION

In connection with the establishment of new long-term tillage trials in 1977, we decided to attempt the unheard-of; namely the planting of potatoes directly in untilled cereal stubble! The first year's results were so encouraging that this method were tried in the following years also (1). In 1987 we observed that the system delayed plant emergence, developement and senescence in a trial at Kise which had not been ploughed since 1979. This prompted further investigations into the effect of harvesting at different times under such conditions. Results of these investigations are presented here, together with results from a trial with direct planting in the presence of chopped straw at a site which had not been ploughed for 15 years.

MATERIALS AND METHODS

Different times of harvesting in a long-term trial
The trial was established in 1979/80 with two tillage treatments - conventional tillage with autumn ploughing versus minimum tillage with spring harrowing only in cereal years, and no tillage at all prior to planting in potato years. Plot size was 10 m X 50 m with four replicates. Spring cereals were grown for the first five years (2), and later also potatoes and

forage crops in alternation with cereals on different parts of the trial. From 1987 to 1993 potatoes were grown after cereals in most years. They were planted with a two-row combine planting machine with ridgers. Harrow tires were mounted between the furrows in order to loosen enough soil to cover the potato setts. An additional ridging was performed immediately afterwards, using a specially strengthened implement while ensured sufficient soil coverage to protect the new tubers from exposure to light. Weeds were combatted either by hoeing or chemically, according to requirements. Blight was controlled with fungicides. Yields of haulm and tubers were harvested by hand on 7,5 m^2 subplots. The soil texture was humus-rich morainic loam. Compound NPK fertilizer was used at a rate of 100 kg N/ha.

Spring harrowing

In the spring of 1992 and 1993 potatoes were planted in a long-term trial, where plots had not been ploughed since 1977. Straw residues had been cut and evenly spread using a tractor-mounted straw chopper the previous autumn. A single pass with a horisontally rotating harrow was made in spring. The purpose of this trial was to investigate the effect of straw residues on yield and tuber quality, especially common scab etc. The soil is loam, similan to the above.

RESULTS AND DISCUSSION

Different times of harvesting in a long-term trial

Table 1. Tuber yields (tonnes/ha) with two tillage systems at three times of harvesting.

	Harvest date						
	26 AUG		9 SEP		23 SEP		Int.act.
	Conv.	Dir.	Conv.	Dir.	Conv.	Dir.	
1987	32.0	28.9	37.0	36.9	34.9	38.8	P<0.05
1988	29.5	29.4	34.1	35.8	33.0	36.0	P<0.05
1989	26.1	24.9	28.9	29.6	29.4	31.5	P<0.01
1990	30.5	29.2	36.0	33.3	37.3	35.8	
1991	21.4	19.7	24.7	22.9	24.8	24.8	P<0.05
1992	22.6	21.2	28.2	27.6	34.0	36.8	P<0.01
1993	28.8	28.4	32.6	33.1	35.1	38.3	P<0.05

Conv. = conventional tillage Dir. = direct planting
Int.act. = interaction

Harvesting was performed at fortnightly intervals from late August to late September. At the first harvest, around 26 August, yields were always greatest following conventional tillage. In one year (1990) this trend continued throughout, but in all other years the yields with direct planting were equal or greater than with conventional tillage by the time of the last harvest, around 23 September. This interaction between tillage and harvest date was significant in six years (Table 1), indicating better competitiveness of direct planting with later harvesting (Figure 1). The tuber yield increase during the harvest period was therefore greatest following direct planting. Between late August and mid-September it was 339 kg/ha/day with conventional tillage and 407 kg/ha/day with direct planting, whilst from mid-to late September it was 82 and 272 kg/ha/day respectively.

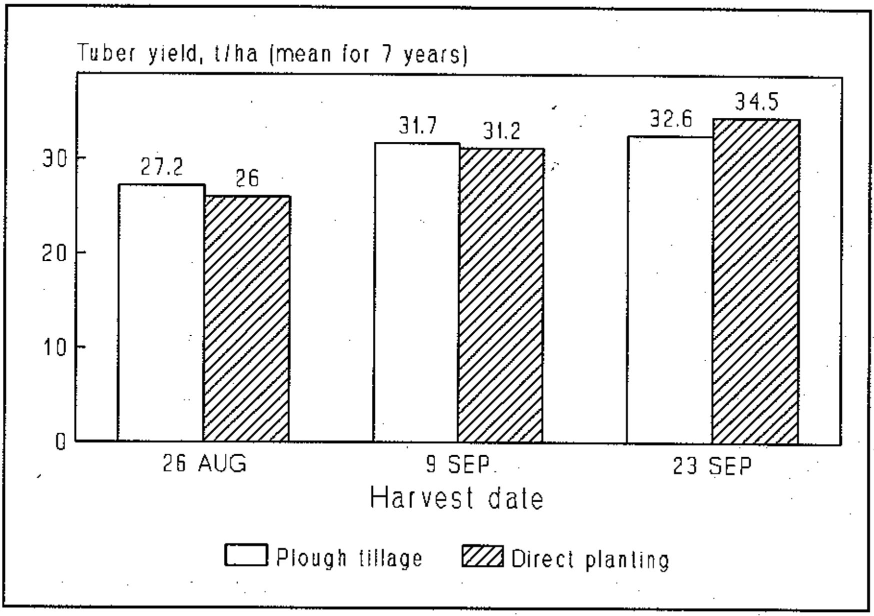

Figure 1. Tuber yields with two tillage systems at three dates of harvesting. Mean for the years 1987-93.

The number of varieties included in the trial differed between years. In 1987 cv. Laila was used and in 1992 and 1993 cv. Pimpernel. In other years three or four other varieties were included as well (Beate, Saturna, Kerr's Pink or Mandel). Laila and Pimpernel were used together in four years in order to establish whether early or late varieties are best suited for direct planting. Results to date have not indicated any difference between varieties in the pattern of yield development in autumn.

At the latest harvest time, the DM yield response of direct planting versus traditional tillage was dependant upon the mean temperature in August:

$$Y = 340 - 22.1 * X \quad (r = -0.97, P<0.001, n = 7)$$

Where Y = yield response, kg/ha
X = mean temperature in August, °C

The equation tell us that in our experiments the response was zero when the mean temperature in August was 15.4 degrees Celsius, and that lower temperature give higher DM yield response for direct planting.

Table 2. Some analyses of yield components and quality for two tillage systems at three times of harvesting. Mean values 1987-93 (N-analysis 1988-93).

	Harvest date								
	26 AUG		9 SEP		23 SEP				
	Conv.	Dir.	Conv.	Dir.	Conv.	Dir.	T	H	TxH
Tuber DM, %	22.7	22.1	24.1	23.7	24.6	24.4	*	**	
Tuber DM, t/ha	6.16	5.54	7.59	7.36	8.01	8.41		***	*
Mean tuber, g	77	77	84	90	89	93			
Green tubers, %	6	6	6	6	6	7			
N in tubers, %	1.19	1.26	1.17	1.24	1.19	1.24	*		
N in tub.kg/ha	71	71	86	89	95	103		***	
Haulm DM, t/ha	2.1	2.4	1.9	2.3	1.6	2.1	***	**	
N in haulm, %	2.35	2.56	2.09	2.23	1.97	2.04	**	**	
N in haulm, kg	49	60	41	53	32	43	***	***	
N in plant, kg	120	131	127	142	127	146	***	*	

Conv. = conventional tillage   Dir. = direct planting
T = tillage treatment   H = harvest date
* = $P<0.05$ ** = $P<0.01$ *** = $P<0.001$

There was a visible delay in emergence in spring and haulm development during the growing season in some years. The haulm was greenest and most abundant following direct planting from mid-July onwards. This resulted in greater haulm quantities, higher nitrogen concentrations and late haulm senescence in autumn with that treatment. The explanation for this may be connected with lower soil temperatures and higher soil moisture contents early and late in the growing season. Soil samples taken in 1987 showed an accumulation of organic matter and total nitrogen on the unploughed plots (3). This may also in part explain the enhanced growth.

Tuber dry matter concentration was greatest following conventional tillage at the earliest harvesting, but later are this difference diminished, and total DM yields was greatest with direct planting.

In some years there were significantly fewer tubers per plant after direct planting. In such cases mean tuber size was increased, giving a higher proportion in the highest price grade. In economic terms, this would give a substantially greater benefit from direct planting than that indicated by yield figures alone, if the potato were sold for fresh consumption.

A very important factor for marketability is the incidence of tuber greening. In some cases the whole plot yield was washed and inspected, whilst in other cases 5 kg samples were taken of the different tuber grades. All tubers with an indication of greening were rejected. In very few cases did direct planting give any increase, and overall there was no difference (Table 2).

No difference was found between tillage systems in the incidence of potato blight, bacterial soft-rot, commom scab or inner tuber defects.

The tubers also had highest concentration of nitrogen following direct planting. At the latest harvest the potato plants had 19 kg/ha more nitrogen after direct planting than after conventional tillage.

Spring harrow

Table 3. Tuber yields and some quality parameters of two potato varieties grown with two tillage systems at Kise in 1992 and 1993.

	cv. Pimpernel		cv. Laila	
	Conv.	Harr.	Conv.	Harr.
Tuber yield, t/ha	34.5	34.3	44.1	44.8
DM, %	27.9	28.1	22.6	22.9
Green tubers, %	0	0	7	5
Common scab, %	5	4	4	4

Conv. = conventional tillage
Harr. = one pass with harrow in spring on unploughed soil with chopped straw.

There was no difference in either yield or quality between the different tillage treatments in this trial. Despite very dry conditions in May and June, the yield level was high due to plentiful rain in July and August. The large amount of straw present in the ridges had no harmful effect on either yield, tuber size distribution or tuber quality. (Table 3).

CONCLUSIONS

It was often earlier maintained that potatoes needed loose soil conditions for good growth (4, 5). Recent research findings have not, however, demonstrated any effect of deep ploughing or subsoil loosening on yields or quality (6, 7). The present results have shown that direct planting of potatoes in unploughed soil often causes delayed emergence, growth and haulm senescence relative to conventional tillage, but that yield levels are nevertheless often higher provided harvesting is postponed long enough. These effects were most noticeable in a long-term trial where soil organic matter had accumulated in the upper horizon. Analyses of haulm and tubers revealed higher concentrations of nitrogen in plants grown on unploughed soil. It is reasonable to assume that this tillage systems has, over time, led to a delayed and possibly slightly increased net-N-mineralisation in late summer. Such a development would have the same effect as split fertilizer application, which is known to give delayed plant maturation.

Direct planting may involve a certain risk of insufficient soil cover to protect against tuber greening. In these trials a single ridging after planting was sufficient to ensure against this.

In some trials, direct planting resulted in fewer and larger tubers. For these reason some varieties should possibly be planted with closer spacing when grown in this way, compared to conventional tillage. Future research will give more information on this.

The findings presented here indicate that it is much simpler to succeed with ploughless tillage in potatoe-growing than in cereal production. Weed problems in particular are easier to tackle, since the top 10 cm soil layer is disturhed both by ridging in spring and by lifting in autumn. One has also the opportunity of using mechanical weed control during the growing season. In the 16 years that we have had trials with this system at Kise, the result has always been satisfactory compared with conventional tillage. In the few cases where growers have had poorer results, it has always been easy to find an explanation - such as incorrect machine adjustment, or excessive prior soil compaction.

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LONG TERM EFFECT OF DIFFERENT SOIL MANAGEMENT SYSTEMS UPON CROP YIELDS AND EFFICIENCY OF CROP ROTATIONS

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ABSTRACT

Influences of long-term use of different soil cultivation systems on crop yields and crop rotation productivity were studied at Hrušovany near Brno a chernozem soil region of south-east part of Czech Republic in 1968-1993. The results show, that minimal soil cultivation systems including drilling to the uncultivated soil are suitable on chernozem soils of semi-arid regions of Central Europe. The yields of crops and productivity of crop rotation are the same no matter what system of soil cultivation is used. The only differences are the requirements for costs and energy for the benefit of minimal soil cultivation technologies.

INTRODUCTION

Advance in soil cultivation technologies is forced by economical pressure on decreasing of all inputs and ecological requirements on saving of soil properties. Farmers give up expensive traditional technologies and adopt new rational minimal and soil protecting ones. Those technologies which are represented by decrease of intensity and depth of soil cultivation, integration of operations, drilling into shallow cultivated or in extreme case into uncultivated soil are ment for cereals particularly (7).

Results of minimal soil cultivation technologies in Czech Republic show, that the growth dynamics of winter wheat, spring barley, spring wheat and maize for grain are the same when grown in both, conventionally or minimally cultivated soils. Also yields did not differ, but savings of costs and energy are considerable (6,7). The ackerage of soils suitable for these technologies overtops 2 mil. ha in Czech Republic (5).

There is a large data collection concerning all aspects of minimal and zero tillage from 1966 till today available in our Institute. More than 300 final research reports were defended there and hundreds of scientific papers were published. The most important finding influencing this research is, that cereals do not respond essentialy to deeper soil cultivation (3) and they prefer soil rather compact than loose to their growth (4).

This paper presents results of the influence of long term use of minimal soil cultivation technologies on crop yields and crop rotation productivity.

MATERIALS AND METHODS

The experimental fields of the Department of Soil Management at Hrušovany near Brno (221 m above sea level) are situated in a region of the corn producing type of southern Moravia, climatologically classified as midly warm and subhumid. The annual mean air temperature is 9.0°C and the annual precipitation (means for 1971-1990) amounts to 466 mm.

According to the data in Table I, there is a considerable decrease of the precipitation amounts and increase of the mean air temperature at the same time in period 1971-1990 compared to the period 1961-1970. This trend continues in the nineties. The soil is chernozem (0-0.6m) on loes (0.6-1.2 m) over sand.

Three intensities of soil cultivation were used for cereals in a six-course crop rotation with 50% of cereals (sugar beet, spring barley, lucerne, lucerne, lucerne, winter wheat, winter wheat). System 1: conventional soil cultivation (post-harvest stubble cultivation and ploughing to 0.22 - 0.24 m depth), System 2: minimal cultivation (shallow ploughing to 0.12 m depth) System 3: zero-tillage (direct drilling with a triple disc drill)

Conventional soil cultivation was used for sugar-beet in all three systems and shallow tillage only in System 3 after lucerne. All other treatments (seed rate, sowing date, rates of pesticides and nutrients etc.) were common with all systems. The experiments were laied out in 1968. This paper shows data since 1974, after finished first rotation. Then the evaluation is done in five - year periods.

RESULTS AND DISCUSSION

The weather conditions of the year and the amount and distribution of precipitation above all have a distinct effect on crop yields. That is the main reason of differences between yield levels and crop rotation productivity in each of all five-year periods. Yield relations of all crops within these periods were stable on balance of three studied soil cultivation systems (Table II.-VI.).

Our results concerning the yields of all crops under study show, that soil cultivation is that soil management treatment, which influences the yielding of crops very slightly. The similar results presented Černý et al. (1) and they were also sustained in our former results from different agroecological conditions (7,8,2).

The mean yields of spring barley after sugar beet as a forecrop and yields of winter wheat after lucerne or winter wheat show only small differences on balance of all three soil cultivation systems. It is true of mean yields for all 20 years as well as for each of all five-year periods. If there is a distinct tendence to get slightly higher yields of cereals using traditional soil cultivation compared to zero tillage, is this effect balanced by increasing of yields of sugar beet and lucerne in zero-tillage system compared to traditional tillage. This increase of yields in zero-tillage system indicates, that long-term use of minimal soil cultivation increases soil fertility parameters, soil structure, quality and quantity of humus particularly (6). Sugar beet and apparently also lucerne are able to utilize these better conditions and give better yields.

CONCLUSIONS

Results of more than 20 years experiments explicitly prove, that minimal soil cultivation systems including drilling to the uncultivated soil are suitable on chernozem soils of semi-arid regions of Central Europe. The yields of crops and productivity of crop rotation are the same no matter what system of soil cultivation is used. The only differences are the requirements for costs and energy for the bebefit of minimal soil cultivation technologies.

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Table I. Hrušovany near Brno - air temperature (°C) and precipitation amounts (mm) 196190

month	1961-1970		1971-1980		1981-1990	
	°C	mm	°C	mm	°C	mm
1.	-2.6	20	-1.1	30	-2.3	25
2.	-0.3	20	1.1	23	-0.8	26
3.	2.9	27	5.0	21	4.1	21
4.	10.0	36	8.4	41	9.1	29
5.	13.8	76	14.2	42	15.0	69
6.	17.6	81	17.2	64	17.5	64
7.	18.5	77	18.5	56	19.9	56
8.	17.5	62	18.4	49	19.2	53
9.	14.7	30	14.1	36	15.0	44
10.	9.5	37	8.5	31	9.5	32
11.	4.6	45	3.5	39	3.0	31
12.	-1.7	24	0.7	20	-0.4	30
1 - 12	8.7	535	9.0	452	9.0	480
4 - 9	15.4	362	15.1	288	15.4	315
10 - 3	2.1	173	2.8	164	2.2	165

Table II. Crop yields crop rotation productivity - mean for 197478

Crop	1. system		2.system		3. system	
	yield	productivity	yield	pruductivity	yield	productivity
Sugar beat	34.043	8.511	34.435	8.609	35.988	8.997
Spring barley	5.009	5.009	4.773	4.773	4.932	4.932
Lucerne 1st year	16.273	2.441	18.713	2.807	17.178	2.577
Lucerne 2nd year	24.449	3.667	24.334	3.650	25.751	3.863
Winter wheat	4.406	4.406	4.351	4.351	4.226	4.226
Winter wheat	4.260	4.260	4.485	4.485	4.044	4.044
mean		4.716		4.779		4.773

yield - $t.ha^{-1}$, productivity - cereal units

Table III. Crop yields crop rotation productivity - mean for 1979-83

Crop	1. system		2.system		3. system	
	yield	productivity	yield	pruductivity	yield	productivity
Sugar beat	36.544	9.136	36.115	9.029	37.738	9.435
Spring barley	4.688	4.688	4.651	4.651	4.294	4.294
Lucerne 1st year	18.371	2.756	19.362	2.904	19.815	2.972
Lucerne 2nd year	21.586	3.238	21.358	3.204	21.966	3.295
Winter wheat	3.973	3.973	3.834	3.834	3.646	3.649
Winter wheat	3.849	3.849	3.902	3.902	4.069	4.069
mean		4.607		4.587		4.618

Table IV. Crop yields crop rotation productivity - mean for 1984-88.

Crop	1. system		2.system		3. system	
	yield	productivity	yield	pruductivity	yield	productivity
Sugar beat	42.276	10.569	44.592	11.148	46.758	11.690
Spring barley	5.710	5.710	5.504	5.504	5.632	5.632
Lucerne 1st year	31.358	4.704	32.508	4.876	31.606	4.741
Lucerne 2nd year	40.765	6.115	39.150	5.873	40.279	6.042
Winter wheat	5.813	5.813	5.850	5.850	5.715	5.715
Winter wheat	6.057	6.057	5.944	5.944	5.876	5.876
mean		6.495		6.532		6.616

Table V. Crop yields crop rotation productivity - mean for 1988-93.

Crop	1. system		2.system		3. system	
	yield	productivity	yield	pruductivity	yield	productivity
Sugar beat	42.585	10.646	43.347	10.837	43.417	10.854
Spring barley	4.015	4.015	4.012	4.012	4.283	4.283
Lucerne 1st year	20.056	3.008	20.084	3.126	19.701	2.955
Lucerne 2nd year	30.210	4.531	29.451	4.418	28.134	4.221
Winter wheat	5.813	5.813	5.850	5.850	5.715	5.715
Winter wheat	4.779	4.779	4.532	4.532	4.503	4.503
mean		5.465		5.463		5.422

Table VI. Crop yields crop rotation productivity - mean for 1974-93.

Crop	1. system		2.system		3. system	
	yield	productivity	yield	pruductivity	yield	productivity
Sugar beat	38.862	9.715	39.622	9.906	40.974	10.243
Spring barley	4.886	4.886	4.735	4.735	4.785	4.785
Lucerne 1st year	21.556	3.233	22.667	3.400	22.075	3.311
Lucerne 2nd year	29.252	4.387	28.573	4.286	29.034	4.355
Winter wheat	4.798	4.798	4.788	4.788	4.564	4.564
Winter wheat	4.736	4.736	4.716	4.716	4.627	4.627
mean		5.291		5.305		5.314

ALTERNATIVE WEED CONTROL STRATEGIES WITH CONSERVATION TILLAGE SYSTEMS IN SOYBEANS

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ABSTRACT

Soybean producers need information on effective weed control strategies in conservation tillage systems that permit reductions in herbicide inputs without sacrificing yields. Field studies were established in 1991 and again in 1992 at two locations. The tillage treatments were fall moldboard plowing (MB), fall chisel plowing (CP), and first-year no-till (NT). Residual herbicides applied broadcast were compared to combinations of reduced rates or banded applications of residual herbicides with mechanical weed control (rotary hoeing plus inter-row cultivation). Rotary hoeing reduced broadleaf weeds in MB and CP treatments, but was not effective in NT. Lowering the rates of herbicides provided acceptable weed control in NT, but was inconsistent with plowed treatments. Although the field operation of the inter-row cultivator was successful in NT, it did not enhance weed control over that provided by herbicides alone. Weeds emerged later with NT, and lower annual weed biomass was present at harvest with NT than with the plowed treatments. Lower input weed strategies (eg. banding, lower herbicide rates and mechanical cultivation) can be successful in conservation tillage systems.

INTRODUCTION

Soybean producers are well aware of the benefits of conservation tillage which accrue from reduced soil erosion, labour requirements and trips over the field. However, one limiting factor for the adoption of conservation tillage in Ontario and the United States has been the perception of weed problems and higher chemical usage (4,5). Furthermore, environmental and economic concerns of herbicide use have increased interest in reducing herbicides using mechanical treatments alone or combined with reduced herbicide rates and/or herbicide banding. Information regarding these weed control strategies would give growers additional impetus for change to more sustainable practices.

Inter-row cultivation has been beneficial when herbicide rate or effectiveness has been reduced (1). Furthermore, timely rotary hoe operation(s) can delay the need for, and improve effectiveness of subsequent cultivations (1). However, there is little data to determine whether these strategies deliver effective weed control in conservation tillage. The objective of this research was to evaluate weed and soybean responses in conventional, reduced, and no-tillage systems to rotary hoeing, inter-row cultivation, and pre-emergence herbicides applied either by broadcasting or banding in conjunction with mechanical treatments.

MATERIALS AND METHODS

Field experiments were conducted during 1991 and 1992 on loam soil at the Elora Research Station (2600 Ontario Corn Heat Units), Ontario, Canada and on private farms near Woodstock (2800 Ontario Corn Heat Units), Ontario. The soil at all sites contained between 3.4 and 4.6% organic matter. Experiments were newly established each year following corn that was harvested for grain. Prior to experimentation, the sites at Elora were conventionally tilled (i.e. MB); while conservation tillage was practised at Woodstock locations (i.e. CP). Common lambsquarters (*Chenopodium album* L.) was the predominant broadleaf weed species at all sites. Pigweeds (*Amaranthus* spp.) were also present at every site. Common ragweed (*Ambrosia artemisiifolia* L.) was present only at Woodstock. Grasses were not prevalent at any site.

Treatments were arranged in a randomized complete block design in a split-plot arrangement with four replications at each location. Three tillage systems were the main plots (21.3 by 21.3 m) which consisted of fall moldboard plowing (MB) to a depth of 15 cm; fall chisel plowing (CP) to a depth of 12 cm; and no tillage prior to planting (NT). Seedbeds in the MB and CP systems were prepared just prior to planting with two passes of a field cultivator to a depth of 8 cm. NT plots received a burndown treatment of glyphosate at a rate of 1.78 kg a.i. ha^{-1}, or paraquat at a rate of 0.80 kg a.i. ha^{-1}, prior to planting. Burndown treatments were applied within 7 d of planting to ensure a weed-free seedbed. Soybean varieties 'Maple Glen' and 'KG60' were planted in 0.76-m-wide rows at Elora and Woodstock locations, respectively, at 400,000 seeds ha^{-1}.

Seven weed management treatments were the sub plots (3.0 by 21.3 m) which included one pass with a rotary hoe, followed by two passes of an inter-row cultivator (mechanical); the pre-emergence application of linuron plus metolachlor broadcasted at 1.08 and 2.40 kg a.i. ha^{-1}, respectively, (full rate) with or without subsequent mechanical treatments; those herbicides applied at 0.76 and 1.68 kg a.i. ha^{-1}, respectively, (reduced rate) with or without mechanical treatments; those herbicides applied in a 25 cm band over-the-row followed by mechanical treatments (banded); and a weedy control treatment where no post planting weed treatment was imposed.

Soybeans were rotary hoed when bean cotyledons were above the soil surface (out of the crook stage), but before primary bean leaves expanded. In general, this was done within 19 DAP in all tillage treatments at each location. Effectiveness was evaluated 1 d prior to cultivation by weed counts in 6 quadrats (0.5 m x 0.76 m), randomly placed in each plot. Inter-row cultivations were made with a cultivator equipped with one 50-cm sweep per inter-row space and two discs adjacent to each crop row to remove weeds close to the crop. The cultivator was adjusted to minimize soil and crop disturbance and at the same time provide maximum weed removal. The timing of the first cultivation was based on stage of crop growth while the timing of the second cultivation occurred at most locations 10 d after the first.

Weed density was calculated from weed numbers recorded in at least 15 randomly placed quadrats (0.38 m^2) per plot near the R2 stage of soybean development. Approximately 2 wk prior to harvest, aboveground weed biomass was clipped at the soil surface from a fixed quadrat (> 4.5 m^2) at the front of each plot. Soybean yield samples were harvested from 7 m of the two centre rows per plot. All weed and soybean seed samples were dried to 0% moisture. Individual year data are presented due to significant treatment by year interactions.

RESULTS AND DISCUSSION

Weed Response

Residual herbicides broadcasted with no subsequent mechanical treatments provided better control when applied at the full rate compared to the reduced rate, especially in the MB and CP treatments. In general, a high degree of broadleaf control was obtained in NT at most locations with herbicides broadcasted alone (i.e. no subsequent cultivations, Figures 1 and 2). However, favourable rainfall amounts received within 10 d following herbicide application contributed to this high herbicide performance. Herbicide efficacy was poor in other studies where there was insufficient rainfall to activate the herbicide (3). The degree of weed control following the application of herbicides at the reduced-rate in NT and CP without mechanical control may be different than that reported here if dry conditions had followed herbicide application.

In general, broadleaf weed control was excellent in all herbicide plus mechanical treatments in all tillage systems, regardless of whether herhicides were broadcasted at the reduced rate, or applied in a band (Figures 1 and 2). The actual reduction in herbicide inputs ranged from 30 to 67%, compared to the full-rate broadcast herbicide treatment. This treatment combination generally provided more effective and consistent weed control than mechanical or berbicide alone (1).

The effectiveness of mechanical treatments, where herbicides were applied, depended on the tillage system. In this study, mechanical weed control treatments consisted of one pass with the rotary hoe and two passes with an inter-row cultivator at most sites. The rotary hoe did not appear to reduce weed numbers in NT (data not shown). In MB and CP systems, the rotary hoe reduced the weed population more than 68% ($P<0.001$) compared to those that were not rotary hoed (data and contrast not shown). The rotary hoe was better suited to MB and CP systems where weeds germinated rapidly and emerged uniformly (data not shown).

The efficiency of the inter-row cultivator for weed control tended to be lower with conservation tillage compared to conventional systems (Figures 1 and 2). This may be due to: (a) high amounts of residue on the soil surface which protect uprooted weeds from desiccation; (b) large clods created from cultivation of soils that were planted with NT (weed seedlings may survive on clods); and (c) the stimulation of dormant weed seeds with inter-row cultivation. Shallow inter-row cultivation is essential to minimize soil and seedbank disturbance, to minimize the number of clods created and to limit root pruning of the soybean crop. Nevertheless, one or two cultivations may

One of the practical consequences of this research is that inter-row cultivation(s) may be warranted where efficacy of burndown and residual herbicides have been reduced and/or where herhicides are banded. However, the potential contribution of weed seed to the soil seedbank by weed escapes may be a cause for concern. Several studies have shown higher densities and population shifts when some weeds species were permitted to reseed and tillage is reduced (2,4).

Soybean Response

Soybean yields among weed management treatments in NT did not vary significantly ($P<0.05$), regardless of herbicide and/or mechanical cultivation sub-treatments (Figures 1 and 2). In fact, NT yields in treatments of broadcast herbicides, combined with mechanical treatments (most aggressive weed treatment), were only 15% higher than NT weedy controls when averaged across all locations. In comparison, soybean yields in MB and CP increased more than 41% with herbicides broadcast in combination with mechanical treatments compared to weedy controls (Figures 1 and 2). The relative consistency of soybean yields in NT among the various weed treatments can be attributed to low weed pressures inherent in the NT system.

High soybean yields in MB and CP treatments were produced with a combination of mechanical treatments and herbicides, regardless of whether herbicides were banded, or broadcast at the reduced or full rate. Mechanical weed control appeared to increase soybean yields in MB and CP treatments, where herbicide efficacy was low and weed pressure was high, compared to NT.

CONCLUSIONS

Weed management strategies with substantial educations in herbicide application were as successful in no-till as in conventional tillage. Weed densities in weedy controls were lower with first-year NT compared to those in MB and CP treatments. This may allow annual weed management strategies to be more flexible under NT.

Satisfactory weed control and bean yields were obtained in NT with herbicides broadcasted at reduced rates with no subsequent mechanical treatments. The addition of mechanical treatments to NT plots that previously received broadcast herbicides did not appear to influence soybean yields or weed control. Therefore, this research suggests that pre-emergence herbicide rates could be reduced by 30% from the present published recommendations even in wide-row soybeans in the absence of subsequent mechanical treatments. Soybeans could also be planted in narrow row spacings to maximize yield potential with this strategy.

This study evaluated weed control strategies in conservation tillage systems while in transition from conventional-type tillage systems. Long-term weed control in conservation tillage needs to be further investigated if research in integrated weed management is to move in a progressive manner.

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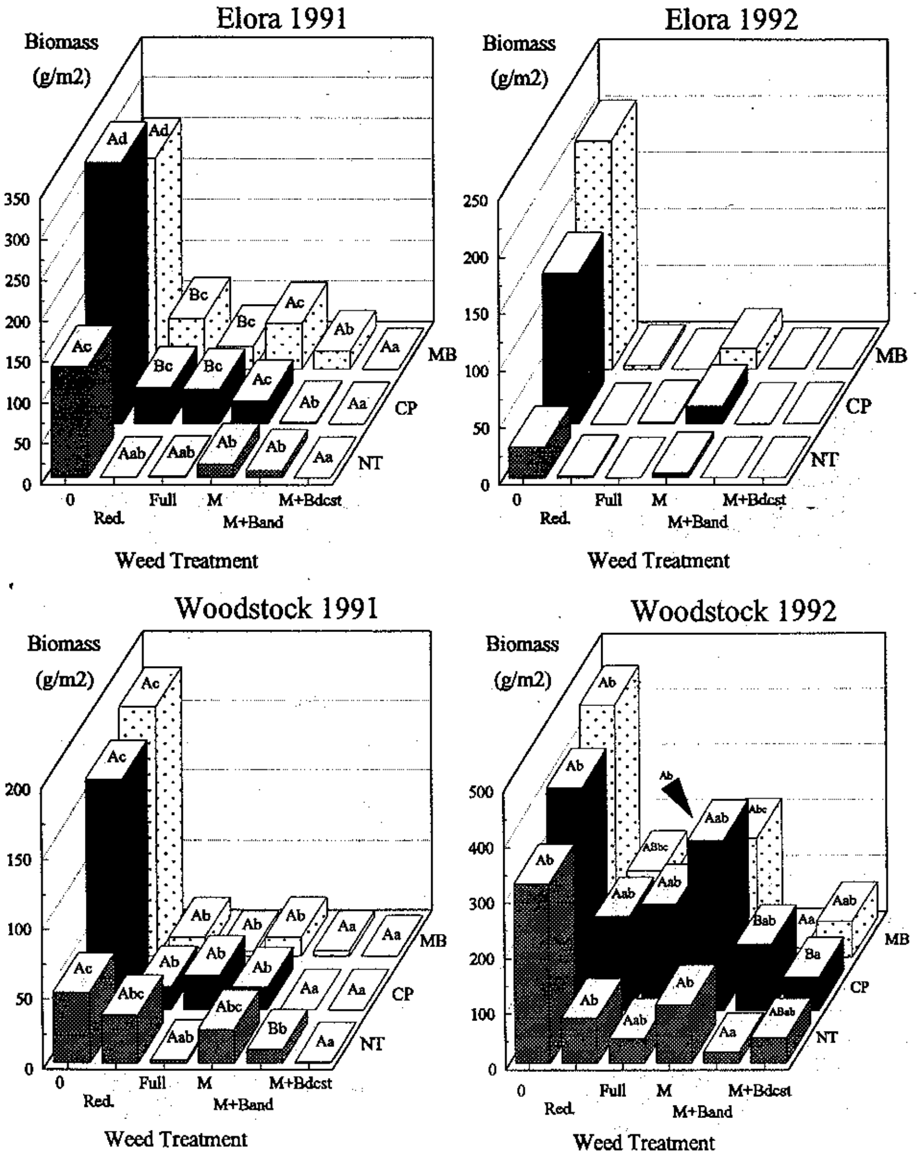

Figure 1. Biomass of broadleaf weeds as affected by weed treatments among three tillage systems at four locations. Tillage treatments within a weed treatment with the same uppercase letter are not different according to LSD (0.05). Weed treatments within a tillage treatment with the same lowercase letter are different according to LSD(0.05).
Abbreviations: MB (moldboard plow); CP (chisel plow); NT (no-tillage)
O (weedy control); Red. (reduced rate herbicide); Full (full rate herbicide);
M (rotary hoe + two inter-row cultivations); Band (herbicide banded);
Bdcst (mena of broadcast herbicides at reduced and full rates)

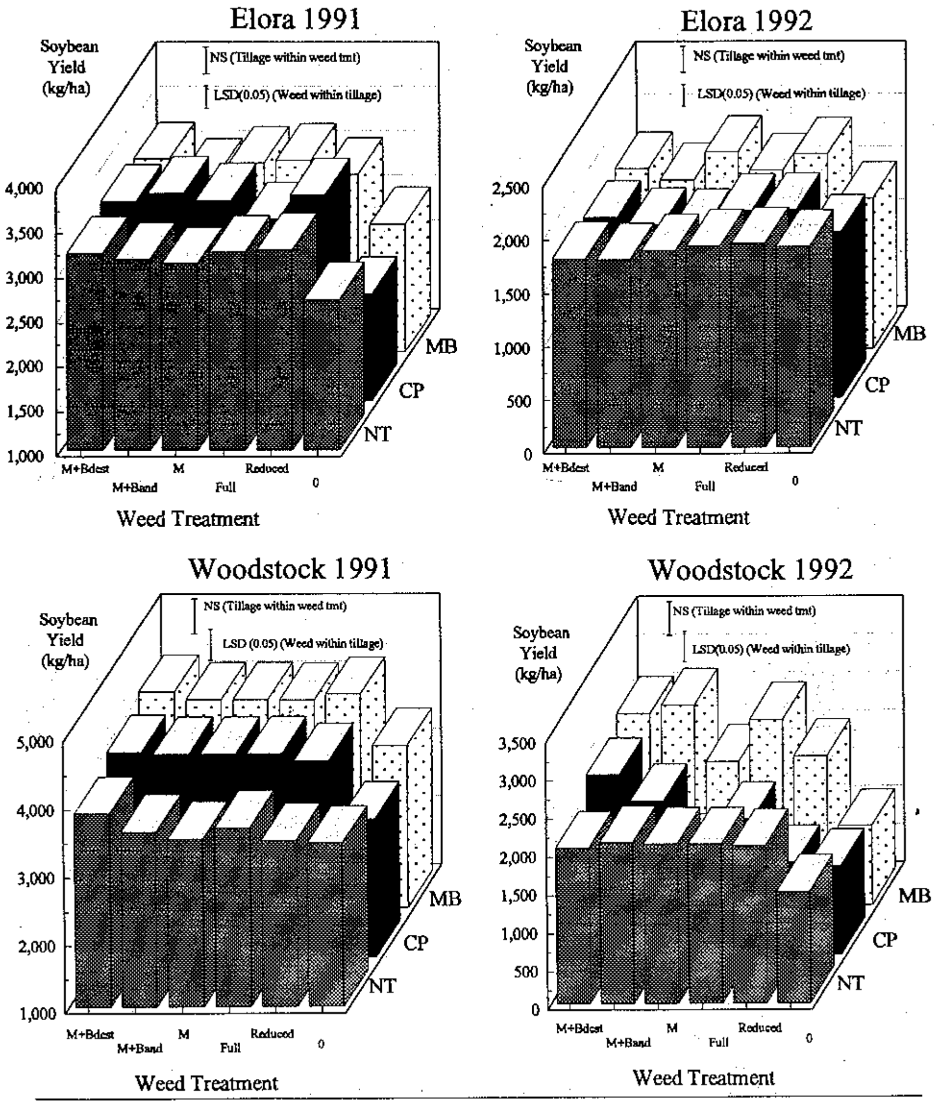

Figure 2. Soybean yield (std. moisture) as affected by weed treatments among three tillage systems at four locations. See Figure 1 for abbreviations.

A multivariate approach to assess the effects of different tillage systems on biometric parameters and weeds in durum wheat continuous cropping.

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Abstract

The trial was designed to test the effects of four different tillage systems (traditional mouldboard ploughing, ripper subsoiling, surface disc-harrowing, minimum tillage with rotary hoeing), combined with three nitrogen doses (50, 100, 150 kg N ha^{-1}) and theree weed treatments (chemical control, mechanical , uncontrollled) on a six-year continuous cropping of durum wheat. The experimental design was a strip-split plot with three replicates.

A multivariate factor analysis was applied to the many variables to quantitative and qualitative production parameters and weed. A physical significance was attributed to the four main factors which accounted for over 80% of total variance: morphological characters, potential quality, grain quality, weeds.

A multivariate variance analysis was tben made on the four factors: the results showed that tillage was always highly significant, whereas fertilization mostly affected potential yield and weeds. In our environment, the traditional mouldboard ploughing has provided the best results.

Introduction

Reducing tillage without causing reductions in productivity or detrimental variations in the agronomic soil properties is an objective which has long been pursued by research. In literature you often find results of experimental works which are not always in agreement with each other because of the heterogeneity of trial environments and of the applied investigation methodologies (Mosca et al., 1986; Toderi et al., 1986; Caliandro et al., 1986, Caliandro et al., 1992, Francis et al., 1993; Pikul et al,, 1993; Benites and Ofori,1993).

The multivariate character of a production process is now fully recognized in that a great deal of measurements of crop properties (morphological, chemical, biological and agronomic) can be derived from a single sample. The complete set of available data is not always fully used, because of the high related costs in terms of time, money, effort and work. There is no doubt that logically correlated variables are generally so highly covariant that one or more of them should not be included in the analysis. The problem is thus to define a limited number of factors which could explain as much of the total variance as possible. Such "factors" or indices should reflect different aspects of the same production process and be sensitive enough to the effect of external factor (tillage, fertilization, climate). In order to assess the reduction in agrotechnical inputs and its effects both on the soil and the crop, a research was initiated in 1982-83, to compare different tillage management systems (Rizzo et., al 1986, Rizzo et al., 1988) of autumn-sown durum wheat (cv. ISA) continuous cropping. This note, in particular, concerns the tillage integrated effects on the major bio-agronomic properties and on the weeds. The production is overlooked in this note since it has been more extensively discussed in a previous work (Rizzo et al., 1992).

Materials and Methods

The research was conducted in 1982/83-87/88 in period Foggia, a typical wheat-grown area in Southern Italy. This pedo-climatic area is characterized by a "Typic chromoxerert" silty-clay soil (according to the USDA Soil Taxonomy classification) and a climate with most rainfall in winter and dry and hot summer, defined as an "Accentuated Thermomediterranean" climate (FAO/UNESCO).

Four different tillage systems (traditional mouldboard ploughing (1), ripper subsoiling (2), surface disc-harrowing (3), minimum tillage with rotary hoeing (4)), three nitrogen fertilizing doses (50-100-150 kg ha^{-1}) and three different weed treatments (chemical control, mechanical c., uncontrolled) were compared on a durum wheat continuous cropping. Measurements were made both on the soil and on the crop through the whole cropping cycle; this note reports only on wheat determinations made at harvest and submitted to the statistical analysis. The common factor analysis was applied to select a limited number of factors without losing a great deal of useful informations on wheat variability. As the crop properties studied were expressed in different units, the risk was to have heterogeneus variances. An important assumption in this analysis involves the homogeneity of variances (Afifi and Clark, 1984). Therefore, wheat property values were standardized with mean equal to 0 and variance equal to 1. All common factors were derived from the matrix correlation rather than from the covariance matrix. Eigenvalues and eigenvectors of common factors were obtained using the "Principal Component" procedure. The number of retained factors was determined by the number of corresponding eigenvalues greater than 1 which accounted for much of the total variability.

After the factors being estimated, they were interpreted, assigning to each of them a name which reflected the importance of the factor in predicting each of the observed variables, that is the coefficients in the pattern matrix corresponding to the factor. To make the factor interpretation less subjective, an orthogonal rotation method, called VARIMAX, was applied to the common factors so that in the rotated pattern matrix nearly all the coefficients were close to 0 or ± 1.

A distinct variance analysis was applied to each of the factors retained after rotation, which resulted to be uncorrelated, in order to test the effects of different tillage, N fertilization and weed treatments. Because of their own nature, tillage treatments have required large plots located in different portions of the field. The estimate of the error might be very poor and the possibility to detect treatment differences very low, because of soil variability so, in order to obviate the problems associated with soil heterogeneity and with the autocorrelation of measurements repeated in the years, a multivariate approach was applied to the variance analysis (Cole and Grizzle, 1966); the multivariate test used in this analysis was Wilk's lambda, which was reported with F approximations. Further details about the methodology applied can be found in a previous paper Castrignanò, 1992.

Results and Discussion

The pattern matrix of the rotated common factors (table 1) has allowed four different groups of bioagronomic variables to be defined in four uncorrelated factors, accounting for about 80 % of the total variance, each of them describing a specified aspect of the crop system. Based on the statistical significance of the coefficients in the pattern matrix corresponding to each factor, the four first common factors were defined as: "morphology", "potential yield", "quality" and "weed control" factor, respectively.

Factor 1 is statistically correlated to the nine following parameters: height measured at the last leaf basis, number of spikelets per spike, height measured at the spike apex and below the spike, number of kernels per spike, straw, spike length, yield and number of kernels per spikelet, with loading coefficients ranging between 90 and 64%. The most influential parameter was the height measured at the last leaf basis, which was shown to be also the most sensitive to agronomic treatments. The other two heights measured at the basis and at the spike apex seemed, based on our experience, to be affected by the weather pattern during the last wheat growth stages which often confounds the treatment effects (De Giorgio et al., 1989). The high correlation of the quantitative parameters "straw yield and "grain yield", with the Factor 1 is due to their close dependence on biometric parameters. Tbe lower coefficient of the number of kernels per spikelet reveals a greater stability of that parameter which resulted then to be less affected by the agrotechnical treatments under test. Factor 2 is positively correlated to the number of fertile spikes and stems per m^2 and is negatively correlated to the number of unfertile spikes. It could be thus used to express the crop yield potential. Factor 3 is mostly positively correlated to the 1000 seed weight, grain hectolitre weight, yellow berry, and negatively correlated to the number of stunted kernel. The positive correlation between 1000 seed weight, grain hectolitre weight and stunted kernel is very likely to be attributed to water deficits, which often occur in that area causing a reduced nitrogen use. Such a factor could be used to describe wheat quality.

Factor 4 is sharply differentiated from the other ones because it is significantly correlated only to the parameter relating to weeds. Therefore it could be defined as the control factor of the infestation degree. Table 2 shows the significant results of the multivariate analysis relative to tillage effect and tillage x weed interaction, and the results of the classical analysis relating to nitrogen effect and weed x nitrogen interaction for the four factors identified in the previous analysis. It seems evident that tillage affects crop morphology, grain quality and weeds significantly.

Nitrogen seems to be highly significant for factors 1,3 and 4, whereas weed treatments have no effect on the parameters relating to morphology, yield potential and grain quality. Their interactions with nitrogen have, however, a significant effect both on morphology and on grain quality. The analysis of variance, conducted on linear contrasts between each tillage system and the traditional one, for the four common factors retained, provided the results shown in fig. 1. As regards Factor 1, i.e. tbe crop morphological characters most related to production, all the three tillage systems were statistically different from the traditional one which was shown to be the most advantageous, under this aspect of the production process. As far as Factor 2 is concerned, although there is still a highly significant difference between the three tillage systems and the traditional one, the conditions are the reverse. Yield potential is minimum in the traditional tillage, and increasingly higher in subsoiling and surface tillage. As to quality, the two surface tillage systems do not show any statistical difference ($p < 0.05$) from the traditional one which produces, however, the best quality grain, in contrast with subsoiling which seems to be markedly detrimental. As to weed control the three tillage systems are not statistically different from the traditional one, in which higher number of operations allowed weeds to be reduced (negative value of Factor 4).

Conclusions

The common factor analysis, conducted on a multivariate set of bioagronomic parameters, measured on wheat through the six-year period during a trial, aimed to compare four soil tillage systems, enabled to selecte four factors to which a specified bioagronomic meaning was assigned. Each of these uncorrelated factors describes an aspect of the production process which is not considered by the others. The analysis of variance, made for each of the four factors, pointed out that the tillage system and nitrogen fertilization affect crop morphology, grain quality and weeds. Instead, the treatment applied for weed control neither affects the quantitative nor the qualitative parameters of the production process; this is due maybe to the choking effect of the tall-sized cultivar ISA.

The analysis of contrasts pointed out a general differentiation of traditional tillage compared to the other systems in all the aspects considered in the production process. Considering morphology, quantitative parameters, grain quality and weed control, traditional tillage remains, under the specified experimental conditions, the most viable.

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Table 1. Rotade factor pattern.

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4
Plant height up to the last leaf	90 *	23	12	-7
Spiklet per ear	86 *	18	21	12
Plant height up to ear	85 *	34	27	-10
Plant height up to ear base	85 *	34	28	-10
Kernel per ear	84 *	13	33	21
Straw yield	82 *	21	-6	-26
Ear lenght	79 *	-11	-23	-5
Grain yield	66 *	47 *	38	-11
Kernel per spiklet fertile	64 *	6	37	27
Ear per m^{-2}	32	90 *	3	-7
Stem density m^{-2}	39	71 *	-29	-14
Infertile ear m^{-2}	-2	-70 *	-41	-7
1000 seed weight	0	-1	73 *	0
Hectolitre weight	41	43	66 *	12
Yellow berry	6	-37	45 *	-26
Stunted kernel	-44	-14	- 76 *	12
Weed matter	-3	-6	-8	89 *

(*) Printed values are multiplied by 1000 and rounded to the nearest integer values greater than 0.407 have been flagged by an '*'.

Table 2. Results of varaiance analysis for the first four principal factors.

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4
TILLAGE	49,28 *	8,04 n.s.	81,06 *	33,31 *
TILL. x WEED	1,82 n.s.	1,33 n.s.	1,59 n.s.	22,87 *
NITROGEN	317,79 ***	5,008 n.s.	178,18 ***	35,45 **
WEED	0,228 n.s.	8,2 n.s.	8,6 n.s.	529,17 ***
WEED x NIT.	4,81 **	2,67 n.s.	4,93 **	2,67 n.s.

Significantly different for $p<0.05$ (*) and for $p<0.01$ (** ; ***). Not significant for $p<0.05$ (n.s.)

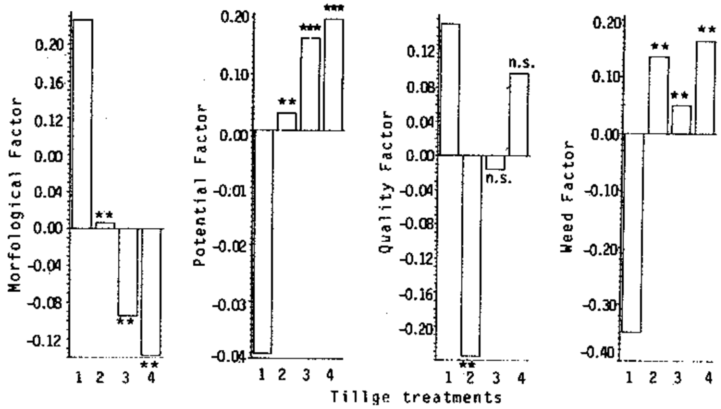

Figure 1. Histogram of means by tillage for the factor 1,2,3 and 4, respectively traditional mouldboard ploughing; ripper subsoiling; surface disc-harrowing; minimum tillage with rotary hoeing. (** contrast is significant for $p<0.01$; *** contrast is significant for $p<0.001$; n.s. not significant for $p<0.05$).

INTERNATIONAL SOIL TILLAGE RESEARCH ORGANIZATION

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W E E D   C O N T R O L   A S   A   B A S I C   A I M   O F   S O I L   T I L L A G E

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ABSTRACT

We keep the point of view that the field crops of cultural plants are plant associations or so called agrophytocenoses. We also determined that the total mass of crop and weed mass in those associations is relatively constant in the same conditions and may be described as a law by such equation: A=Y+Xb or Y=A-Xb (A- maximum productivity of the association; Y-crop yield; X-weed mass, and b-depression coefficient).According to that law,the soil tillage, chemical , biological and other means of weed control influencing the yield increase it at the degree they decreace the mass of weeds in the association, if the metod does not disturb the crop plants. For that purpose the constructions of soil tillage technique must be applied, especially constructions of ploughs, becouse the weed control is the basic aim of soil tillage.

INTRODUCTION

Manuals of agriculture have been claiming for more than hundred years that the main aim of soil tillage consists of changing physical characteristics of the soil and activation of chemical and biological processes whereas the weed control remains a second rate task. Such succession is so far included into the scool programs; and the design of agricultural implements and their working parts is directly influenced by it. Nevertheless, the publications of the data and practical experiences reveal that after extermination of weeds by means of herbicides and other effective measures the mechanic soil tillage and its hoeing become meaningless . This enables to minimize the tillage or to refuse it completely. And the yield of agricultural production decreases inconsiderably or remains unchanged. Most often the physical and the biological characteristics of least cultivated soil equal or are even better than those of traditionally cultivated one. It is impossible to explain these contradictions referring to the postulates of traditional agriculture wich is based not on the theoretical but on the empiric approach. Empiric reserch is subject to fix what it is possible to perceive, to weigh or to touch by any other means, and theoretical premises are rarely used. The prevailing cognition of agricultural science was determined by the rise and development of agricultural practice which started thousands of years before scientific foundation of agriculture was laid. Thus the science of agriculture did not become the base for the creation of agricultural implements and new technologies. It was only to give the technologies a scientific explanation.

In the time of the Roman Empire when the mineral nutritious matter was yet unknown, the necessity of soil tillage was related with the well-known factors influencing yield , extermination of weeds and humidity preservation. Later on, after defining how sunlight, air , mineral nutritious matter and microorganisms influence the growth of the plants, soil tillage was attributed the regulation of those factors and this regulation was declared the main aim of soil tillage. That is way up to now in the tillage experiments trials most often the physical characteristics of the soil are being examined in detail, and no attention is paid at how the experimental measures influence the weed mass. The matter is that the weeds equal the cultural plants as concerned their growth conditions. And under the more favourable growth conditions they are the first to take advantage of them which means that cultural plants are left less conditions. On the contrary, if the growth of the weeds is given difficulty by soil tillage or they are even extermined, the cultural plants take better advantage of the vegeta tion factor for the growth of plants, their yield is increasing, whereas the mass of the weeds is decreasing. Nevertheless , the productivity of the whole community which is expressed in the total mass of weeds and cultural plants in the same conditions remains relatively constant. That is why examining the productivity of only one component of a plant community - cultural plants -the view of the phenomenon is incomplete and not always objective which hampers the development of scientific theory of agriculture . Because of abscence of such theory in the East European countries the ploughs are inefficient and other outdated agricultural implements are so far used which favours the survival and spreading of the weeds, and this causes a great damage to the economy of those countries. This is the reason of using the bigger quantities of herbicides and the pollution of the environment. In the Western countries the private property of land, experience and private initiative form the interest for market and industry through demand. Therefore the agricultural implements which helped the farmers tocontrol weedness of crops had greater demand. But even these implements are to get a theoretical estimation.

MATERIALS AND METHODS

The experiments were carried out during the period of 1963-1990 at the Experimental Station of Lithuanian Agricultural Academy, near Kaunas town. To prove the universality of the original law of crop performance the author used for calculation a big quantity of experimental data carried out by many authors and published in different places of the world.

RESULTS AND DISCUSSION

The aim of experiments was to establish the relationship between the mass of weeds and the yield of cultural plants. The initial point was the premise that the crop of cultural plants is a plant association in which two groups of the plants prevail - the man sown cultural plants and the original field plants -the weeds. This premise is based on the fact that both weeds and cultural plants have the similar chemical structure and their growth require the same factors for vegetation. The experiments revealed that when the mass of the weeds in a plant association is changing (fig.1) correspondingly, only in the opposite direction, the mass of the cultural plants is changing (fig.1a) but the total mass of the whole association remains relatively constant (fig.1c). The differences between the yield of barley and the mass of Sinapis arvensis between the extreme treatments are significant. On the other hand,the biomass total (barley plus weeds) per pot is relatively stable and the difference of the biomass totale between the extreme treatments is not significant, less than the LSO 95% (the Least Significant Difference).

We can express this phenomen by the negative relationship between the mass of weeds and yield of crop (fig. 2) . It may be described as a law by such equation: $A=Y+Xb$ or $Y=A-Xb$ (A - maximum productivity of the whole association ; Y - crop yield ; X - weed mass and b - depression coefficient of yield caused by weeds). According to that low, all agronomical, biological and, first of all, measures of soil tillage influencing yield increase it at the degree they decrease the mass of weeds in the association if the method does not disturb the crop plants. This law enables us to calculate the damage caused by weeds in the crop. E. g.,in the Lithuanian conditions the depression coefficient of barley yield caused by the weeds (while dry mass of weeds is calculated g/m2, and the yield of barley grains q/h) is about $0.0628 \div 0.0061$. This means that 1 g of dry weeds to 1 sq. m. decreases the yield of barley up to 0.628 g. or, while counting to 1 ha, it makes 0.00628 t/ha. In Lithuanian conditions, 100 g. of dry weeds to 1 sq.m. decrease the yield of barley up to (100x0.00628) 6.28 t/ha. On the contrary, any means of decreasing of weedness of a crop by 1 g of dry weeds, the yield of the crop increases 0.00628 t/ha.

Most of the East European countries used the so called "Cultural ploughs" with short and steep molboards. This type of ploughs is very inefficient to bury seeds and other parts of propagation. In the trial from all the plough types available, the double deapth ploughs were the best to turn the slice over and to decrease the weed mass of crops (fig.3.) Consequently, the highest yields of the crop are gained (fig.4.)

The same can be seen while comparing the means of autumn soil tillage . In the publication B. Kadziauskas and S. Blaziene (1977) about research covered seven treatments (fig.5.); I.- Broken stubble directly after harvesting and ploughing at the end of September; 2.- Broken stubble directly after harvesting and ploughing at the end of October; 3.-Cultivation after harvesting and ploughing at the end of September; 4.- Discing directly after harvesting and ploughing at the end of September; 5.- Ploughing directly after harvesting;

6.- Ploughing at the end of September; 7.- Ploughing at the end of October. The least mass of weeds was in the treatment 1;2;3 and 4. The relationship between the mass of weeds and the yields of grain barley (fig.5a.)and yellow lupine (fig.5b.) was strong and reliable.

Strong and reliable relationship was also found between the mass of weeds and yields of green mass of maize in the data published by Dospechov, Puponin and Karasev (1976) (fig.6.).

On the basis of the above described law of the crop performance and a big amount of data of soil tillage we draw a conclusion that weed control is the basic aim of soil tillage and for that purpose the constructions of soil tillage technique must be applied, especially the construction of ploughs and seedbed preparation implements.

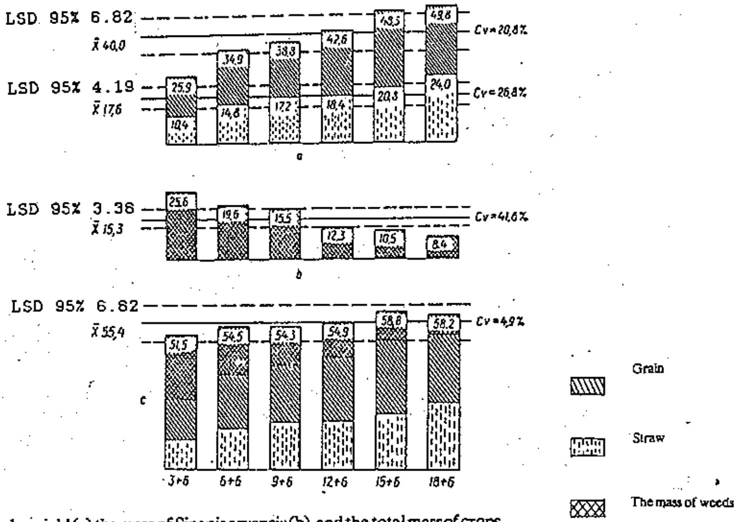

Fig.1.The change of barley yield (a) the mass of Sinapis arvensis (b), and the total mass of crops and weeds (c) by increasing the number of barley plants in the pot.

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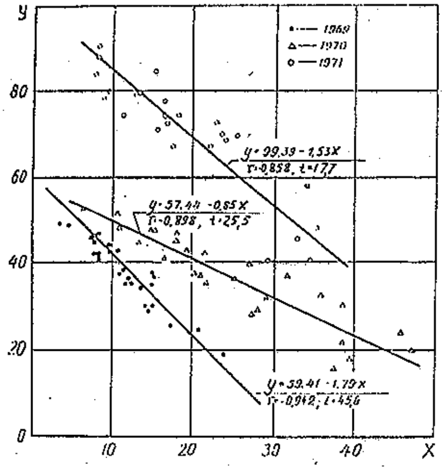

Fig.2. The relationship between the barley grain yield (y, g/pot) and the mass of Sinapis arvensis (x, g/pot) by increasing the number of barley plants in the pot.

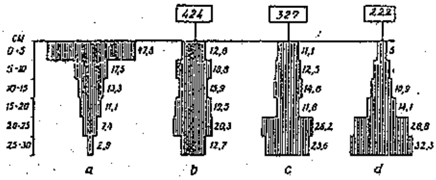

Fig.3. The distribution of weed seeds in soil before ploughing with "cultural" plough (b) , with general purpose plough (c),and with double depth plough (d). Above there is the mass of weeds after ploughing with the same ploughs.

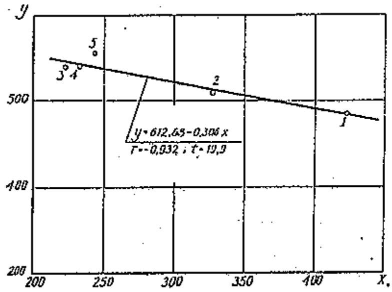

Fig.4. The relationship between the yield of cabbage (y) and biomass of weeds (x) after ploughing with different types of ploughs: 1 -"cultural" plough, 2 -general purpose plough and 3,4,5 -double depth plough.

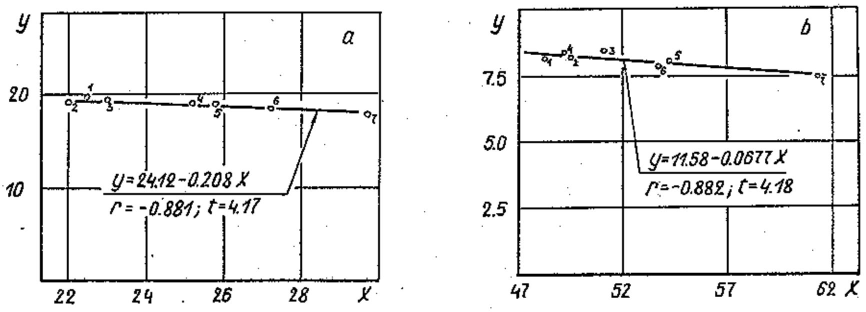

Fig.5. The relationship between the yields of grain (y) of barley (a) and yellow lupin (b) and the mass of weeds (x) applying different stubble broken means.

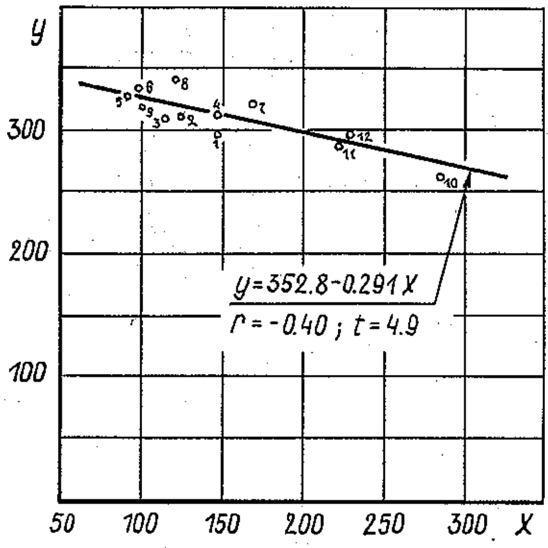

Fig.6. The relationship between the yields of green mass of maize (y) and the mass of weeds (x) applying different system of soil tillage.

Codes of the treatments

Seedbed preparation	Without interrow cultivation	Number of interrow cultivation	
		one	two
Cultivation (twice)	1	2	3
Deep mellowing+cultivation	4	5	6
Strip rotary tillage	7	8	9
Strip rotary tillage without ploughing	10	11	12

A GEOSTATISTICAL APPROACH TO CHARACTERIZE SPATIAL VARIABILITY OF YIELD IN A DURUM WHEAT SUBMITTED TO FOUR TILLAGE TREATMENTS.

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Abstract

Different plots in a trial field often show different responses to the same tillage method owing to both inherent and anthropic soil variability. Geostatistical techniques were appplied to estimate the spatial structure of durum wheat yield after segregating the data by tillage treatments (traditional mouldboard ploughing, ripper subsoiling, surface disc-harrowing, minimum tillage with rotary holing). These treatments were stripped across the 50 m-long field and replicated three times. Analysis of semivariograms for wheat yield showed a different variance structure for each tillage treatment. Maps showing isorithms of the estimated grain yield and its estimation variance were generated for the whole field by using kriging. Patterns of the kriged yields were appreciably different for each tillage treatment. Estimated yield values compared favorably with the measured ones using Jacknife kriging.

Introduction

Differences in crop production at the field level may be caused by both inherent and human-induced soil variability. Natural variation is often related to changes in soil properties, such as solum depth, soil texture and structure, organic matter content, bulk density, saturated and unsaturated hydraulic conductivity, salinity , soil fertility and so on (Hanna et al., 1983; Casssel et al., 1988). Soil tillage may sometimes superimpose human-induced soil variation on natural one, because of, for example, uneven or "spotty" applications of fertilezer and lime, or soil compaction by farmer machines. Plant responds to the total variability of its environment, then, in a trial field, it may be expected the component of the total yield variance, due to inherent changes in soil properties, to he greater than the one imposed by tillage treatments.

Previous studies have applied the theory of regionalized variables to estimate the variability at the field level of some soil physical, chemical and microbiological properties (Burgess and Webster, 1980). In general any soil property can be considered as a "regionalized variable", i.e. a continuous variable whose value changes with location in the field. Semivariograms were used to study the spatial structure of individual soil properties and thematics maps were developed by kriging. The same methodology has been also used to examine the variance structure of other variables of agronomic importance, such as plant dry matter, crop yield, canopy temperature and so on (Bresler et al., 1981; Hatfield et al., 1984).

The objectives of this study were: 1) to utilize the theory of regionalized variables to estimate the field variability of grain yield of durum wheat cropped in Southern Italy and submitted to four tillage treatments; 2) to evaluate the expected wheat grain yield throughout the entire field, obtained by kriging.

Materials and Methods

Durum wheat grain yield data used in this study were those reported by Rizzo et al. (1992), concerning a tillage trial conducted for a six-year period (1982-83/ 1987-88), but restricted to the only year 1988. The purpose of that study was to evaluate the effects of two deep (traditional mouldboard ploughing (1), ripper subsoiling (2)) and two shallow (surface disk-harrowing (3), minimum tillage with rotary hoeing (4)) tillage practices combined with increasing N fertilizer doses on changes in soil physical properties and wheat production.

The different tillage treatments were placed in the largest plots (10 x 95 m), with the longest side in direction east-west, and were replicated three times. The soil was silty-clay, classified as "Typic Chromoxerert" hy USDA Soil Taxonomy and the climate was characterized by hot and arid summers and cold and rainy winters. More details of the experimental mehodology were provided by Rizzo et al. (1992). Geostatistical techniques were used to evaluate the spatial structure of wheat grain yield, both considering the whole field and segregating the data hy tillage treatment. The X and Y coordinates were assigned to the center of each harvested plot (3.33 x 10 m).

Directional semivariograms along the row (E-W direction) and across the row (N-S direction) were computed using the actual yield of the entire field.

Due to the limited number of separation distances along the N-S direction, isotropic semivariograms for each tillage treatment were calculated, using the relative grain yield, given for each plot by:

$$Y_r = Y / Y_{max} \qquad [1]$$

where Y is the grain yield at 15% moisture in megagrams per hectare for a particular plot and Ymax is the maximum yield for all the 132 harvested plots.

The approach followed in determining the sample variograms was similar to that outlined in Journal and Huijbregts (1978). Semivariances were computed only to those lags that provided a minimum of 20 pairs.

One of the following three mathematical models:

spherical model: $$\gamma(h) = C_0 + C[3/2(h/a) - 1/2(h/a)^3] \qquad [2]$$

gaussian model: $$\gamma(h) = C_0 + C[1 - \exp(-h^2/a^2)] \qquad [3]$$

exponential model: $$\gamma(h) = C_0 + C[1 - \exp(-h/a)] \qquad [4]$$

where: γ is the computed semivariance; h, the separation distance; C_0, C and a, costants called nugget, sill-nugget and range respectively, were fitted to each sample semivariogram, using the nonlinear least-squares procedure of Marquardt (1963). The actual grain yield for the whole field and for each tillage treatment was estimated using punctual kriging (Burgess and Webster, 1980). Kriged values were located on a 42 by 95 - m grid (4128 yield estimates) throughout the entire field. Each yield estimate was for an area of soil surface with dimension 1 m wide (the width of 6 wheat rows) and 1 m long. A minimum of ten nearest neighbours was used in kriging. Maps, showing isorithms of the estimated grain yield and its estimation variance, were generated using the punctual yield estimates for the whole field. It could be expected first-order stationarity not to be present on the whole field because of the different tillage treatments. For this reason we preferred to construct separate semivariograms for each treatment to be sure that the hypothesis of short-range stationarity were fulfilled. Yet, from the results of the semivariogram analysis for the whole field (presented in the discussion section) the absence of treatment-induced drift has emerged and so we felt comfortable using kriging for generating maps on the entire experimental site.

The process of jackknifing was used to determine if the kriged grain yields were valid estimates for each tillage treatment and for the whole field. In this procedure every measured observation was left out of the calculation and estimated from the neighbouring values. Simulated and measured sets of values were compared, producing two statistics: the reduced mean error (RME) and the reduced variance (RD) in output, respectively:

$$RME = \frac{1}{M}\sum_{i=1}^{M}(y_i - y_i^*) \qquad [5]$$

$$\mathrm{RD}=\left\{\frac{1}{M}\sum_{i=1}^{M}\left[\left(y_i-y_i^*\right)/\mathrm{KSD}_i\right]^2\right\}^{\frac{1}{2}} \qquad [6]$$

where: M is the number of observation points; y_i, yield measured value; y_i^*, yield estimated value; KSD_i kriging standard deviation. Two basic conditions must be satisfied for the model to be theoretically consistent: 1) there is no sistematic error, i.e. RME $\cong 0$; 2) the kriging variance is consistent with the corresponding error $(y_i - y_i^*)$, i.e. RD $\cong 1$.

Results and discussion

Mean actual grain yield, the variance and the maximum actual yield for the 33 harvested plots for each tillage treatment are presented in table 1. The mean relative grain yield for each treatment is the average of the 33 Yr values calculated using Eq. [1]. The mean grain yield and the variances were similar for the two shallow treatments (3 and 4), whereas the traditional ploughing (1) produced the highest yields with the minimum variance and the subsoiling was the least productive. The distributions of the actual grain yield for the whole field and the relative grain yield for each tillage treatment are resulted normal at the 0.01 probability level of Kolomogorov-Smirnov test. Calculated semivariograms for relative grain yield of each tillage treatment and semivariograms in the-across-the-row and in the along-the-row directions for the actual grain yield of the whole field are shown in fig. 1.

In table 2 the type of the semivariogram model used and the regression parameters are reported. The gaussian semivariogram model for treatment 3 has a nugget significantly different from zero and a very small structural component. Hence the yield variance for the disk-harrowing tillage had little structure, but exhibited a sizeable nugget indicating high random variability, i.e. disking did not create spatial dependence and did not reduce soil physical and hydraulic limitation that occurred more or less randomly throughout the field. The traditional ploughing to the 0.50 m depth reduced the yield variability, that remained random in nature, as indicated by C_0 and C not signicantly different from zero. The effect of mouldboard was similar to that described by Cassel et al. (1978) in that mechanical impedance of the soil after ploughing was more uniform, as evidenced by the smallest nugget value. Therefore, the yield increased because the roots were able to penetrate the disrupted pan and utilize stored subsoil water. The minimum tillage was the only one to have a pronounced variance structure, with the greatest C. The disk and the minimum tillage treatments were expected to have similar variances (table 1), however, only the minimum tillage treatment resulted in a well defined variance structure. Subsoiling reduced C and the yield variability was completely random. A likely explanation is that the ripper operation was sufficient to interrupt soil continuity and then disrupt spatial structure. The directional semivariograms for the whole field, calculated across-the-row and along-the-row directions, showed that the variance structure was not the same in all directions. The yield variability associated with the across-the-row direction was well highly structured, with the random component not significantly different from zero, whereas the along-the-row direction resulted in a much less pronunced variance structure. The total variance was nearly the same in both directions, but the nature of that along-the-row was essentially random.

Yield observations as well as measured soil physical and chemical properties information got from a previous survey (Catrignanò and Lopez, 1988), indicated then that the field was not uniform in all directions, very likely because of a clay gradient in the North-South direction (across-the-row).

Maps, showing estimated wheat grain yield in megagrams per hectare and the estimation variance for the entire field, are shown in fig. 2 and 3. Visual examination of yield map shows that the kriged values were the highest in the ploughing treatment, with the lower half portion of the field more productive. A well defined yield gradient existed from north to south, proceeding from the ploughing to the subsoiling treatment. The effect of subsoiling produced , in fact, the lowest yields for the treatment 2 with a very large roughly uniform zone in the central part of the field (mean yield ≅ 1.2 Mg ha^{-1}). Passing to the adjacent plot, corresponding to the disk treatment, the pattern of yield isolinees changes dramatically. Whereas in ploughing and subsoiling treatments the isolines ran nearly parallel to the along-the-row direction, indicating the existence of a gradient in the across-the-row direction, in the disk treatment the resulting pattern of kriged values appeared very complex and random, with a wide range in yield. Finally, in the plot relative to the minimum tillage, the arrangement of the isolinees was regular, nearly parallel to the across-the-row direction and with a large very productive zone in the upper half portion of the field (yield > 2.2 Mg ha^{-1}). Collectively, the information presented in fig. 2 clearly shows that wheat production varied with position in the field. Furthermore, the expected yield at a given point and the pattern of variation throughout the field were different for each tillage regime.

Tbe grain yield estimation variance (KVAR) patterns were very similar for three tillage treatments: traditional ploughing, subsoiling and disk, but quite different for the minimum tillage. Of the four methods, only the ploughing treatment had a KVAR ≥ 0.40 Mg^2 ha^{-2}, with an arrangement of the isolinees parallel to the across-the-row direction and the highest values near the left border of the field. For the remaining treatments, the estimation variance associated with each kriged value was highly dependent on the distance between estimated and measured (supposed in the centre of the 132 plots) yields and increased as such distance increased. The process of jackknifing was used to determine if the kriged grain yields were valid estimates for each tillage treatment and for the whole field. The jackknifing results, shown in table 3, indicate that the semivariogram models adequately described the variance structure, except the ones relative to the treatment 2 and the along-the-row direction for the whole field because of their lack of structure.

Conclusions

The theory of regionalized variables was used to evaluate durum wheat grain yield response to four tillage treatments. Analysis of semivariograms for relative grain yield showed a different variance structure for each tillage management .The variability associated with the variance for the disk tillage resulted primarily from random variation in the field, presumably caused by variable soil properties, and that little spatial continuity exhisted.

Traditional ploughing uniformly removed the tillage pan constraint and provided a more uniform rooting medium; all variability for the subsoiling treatment was random. The yield variability associated with the minimum tillage was highly structured. Yield maps showed that the production was not uniform throughout the entire field but changed with position.

The weakest point in map construction in our study was the hypothesis that the semivariogram for each tillage treatment were isotropic. Because only three strips for each treatment were measured, we couldn't use directional semivariogram for each tillage. Increasing the number of strips would allow an evaluation of the directional semivariograms throughout the field for each tillage treatment. Use of this technique could result very promising in adding much more information to our knowledge of soil management-plant response interactions.

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Table 1: The mean, variance, maximum harvested wheat grain yield and mean relative wheat grain yield in 1988 as affected by tillage treatment.

Treatment *	**Mean grain yield** ** ($Mg\ ha^{-1}$)	**Variance** ($Mg^2\ ha^{-2}$)	**Maximum yield** ($Mg\ ha^{-1}$)	**Mean relative grain yield** (%)
1	2.88 a	0.36	4.29	67.30
2	1.42 c	0.56	3.25	33.20
3	1.87 b	0.61	3.45	43.73
4	1.81 b	0.66	3.48	42.17

* Traditional mouldboard ploughing (1), ripper subsoiling (2), surface disk-harrowing (3), minimum tillage with rotary hoeing (4).

** The means with the same letter are not significantly different for $p < 0.05$.

Table 2: Spatially dependent parameters and their standard errors (S.E) of actual wheat grain yield for the whole field and relative grain yield for each tillage treatment.

	Model	**Nugget effect** C_0		**Structural component** C		**Range** a	
			S.E.		S.E.		S.E.
Treatment 1	Spherical	0.009	0.013	0.016	0.018	48.74	74.76
Treatment 2	Exponential	0.019	0.057	0.004	0.054	7.43	141.50
Treatment 3	Gaussian	0.027	0.001	0.026	0.055	46.22	80.38
Treatment 4	Spherical	0.011	0.011	0.033	0.011	46.07	26.43
Across-the-row (whole field)	Spherical	6.450	23.000	81.950	24.490	14.15	8.62
Along-the-row (whole field)	Gaussian	68.570	22.420	26.650	24.130	25.20	32.38

Table 3: Results of jackknifing semivariogram models.

	Sum of squares	**Reduced standard error**	**Reduced variance**
Treatment 1	$1.19 * 10^{-4}$	$8.47 * 10^{-3}$	$9.95 * 10^{-1}$
Treatment 2	$1.53 * 10^{-3}$	$4.07 * 10^{-2}$	$8.83 * 10^{-1}$
Treatment 3	$1.50 * 10^{-4}$	$8.44 * 10^{-3}$	1.00
Treatment 4	$1.36 * 10^{-4}$	$3.93 * 10^{-3}$	$9.99 * 10^{-1}$
Across-the-row (whole field)	$6.53 * 10^{2}$	$-1.90 * 10^{-3}$	$9.43 * 10^{-1}$
Along-the-row (whole field)	$3.60 * 10^{2}$	$9.94 * 10^{-2}$	$6.37 * 10^{-1}$

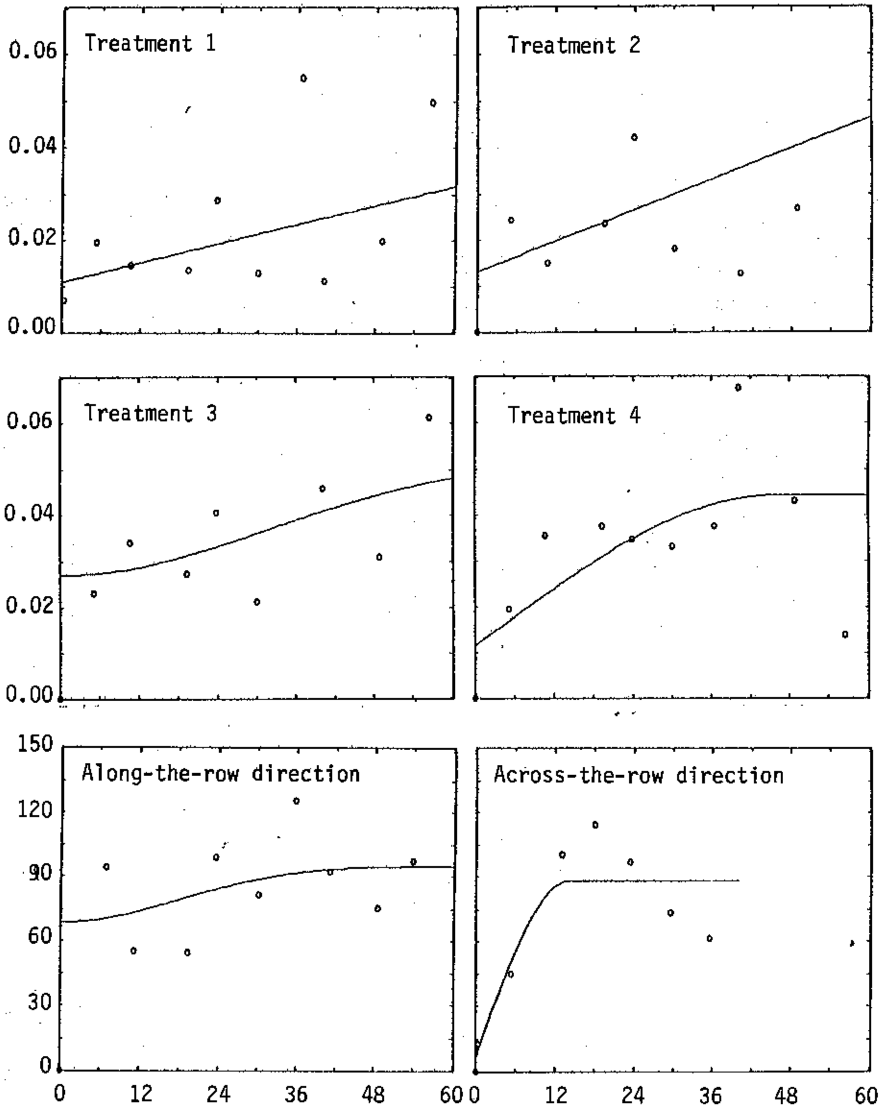

Figure 1: Semivariograms for the relative wheat grain yield for each treatment and directional semivariograms in the along-the-row and in the across-the-row directions for actual wheat grain yield for entire field.

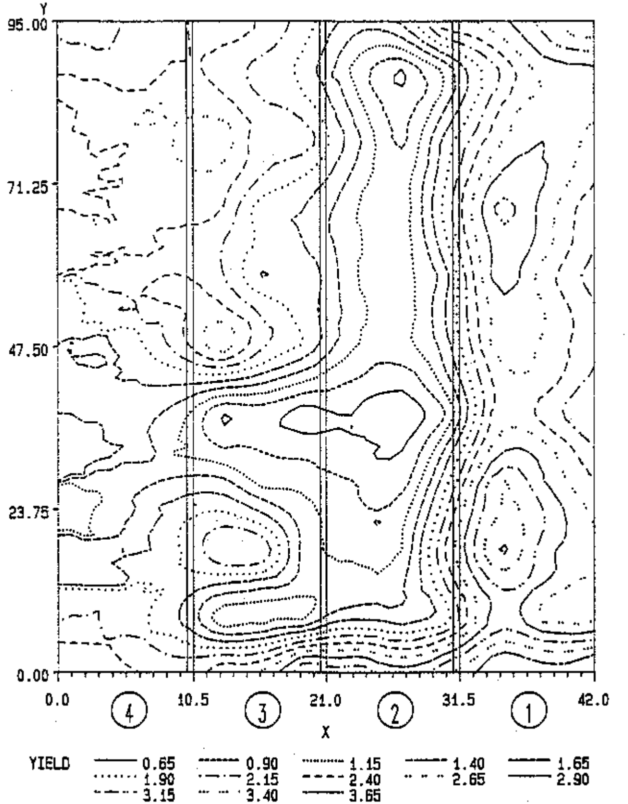

Figure 2: Maps for the actual wheat grain yield throughout the entire field as estimated by punctual kriging (the circled numbers corresponding to the treatments).

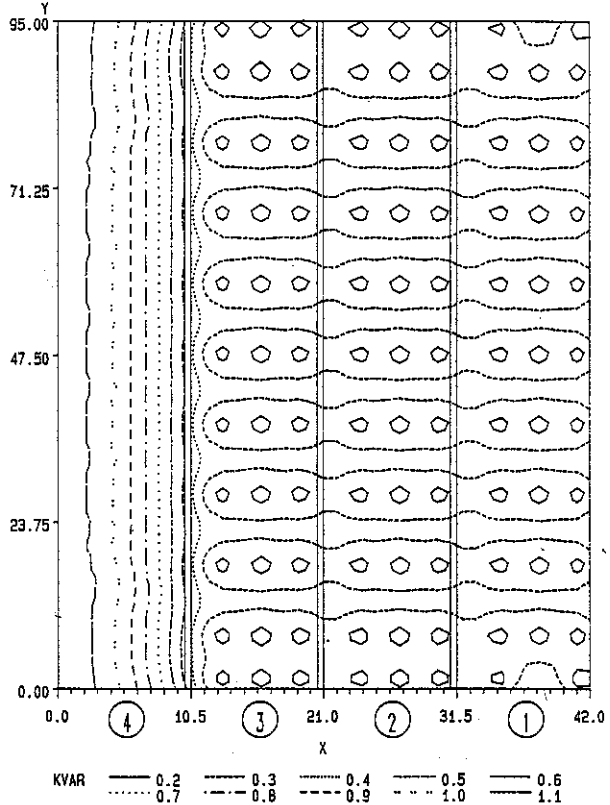

Figure 3: Estimation variance of the wheat grain yield estimated by punctual kriging throughout the entire field (the circled numbers corresponding to the treatments).

Soil Tillage and Sustainability of Rice Cropland

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ABSTRACT

Flooded rice cultivation is widespread in Italy, where topography and availability of water resources are suitable. Rice cropland has been increased during the last decades, and is one of the more profitable cultivations in the floodplains. So, thanks to powerfull machineries, rice is cultivated regardless of soil characteristics, and permeability is artificially regulated creating puddled surface soils (a tilled surface layer and a directly underlying slowly permeable layer).
It is of great importance to inventory the different soil-site combinations in which human activities control soil formation and evolution.
These "man-made" layers affect pedogenesis and influence the soil classification, but they can also limit the sustainability of rice cultivation. These considerations are applied in the western plain of Lombardy (Northern Italy), interpreting a semi-detailed soil survey (scale 1:50.000), and referring to the following subjects:

i) tillage, "man-made" layers and "anthraquic" conditions;

ii) soil tillage in rating cropland for the sustainability of rice cultivation.

INTRODUCTION

The modern techniques of cultivation (lowering, levelling with laser and conservation of the plough- layer) have permitted through flooding to extend the rice cultivation as well on very permeable soils.
The soil survey interpretation can point out the location of the zones where these usages present a major risk for the environmental quality and the sustainability of the agricultural production; in fact the most permeable soils are often given a considerably higher input of fertilizers and herbicides. This influences the economical and environmental equilibrium and can alter with evident swiftness the quality of the water resources.
A first interpretation is presented in this study, which is part of a soil survey in the western part of Lombardy (Northern Italy, Province of Pavia, see the figure). It is still in the fase of revision on behalf of water controlling Authority.
The survey partakes in the largest program of soil cartography of the Region of Lombardy and has a "multipurpose" function. Already in the first part of the work it became clear that the most interesting applications could regard the operative and management directions to render the rice cultivation sustainable. During the execution of this study the new edition of the "Keys to Soil Taxonomy" (5) has been published. So it seemed important to develop a classification model in analogy to the new acquisitions on the control of the anthropic effect in regard to the hydromorphic features in the soil profile.

MATERIALS AND METHODS

In the territory of central-south Lombardy, which has a surface area of more than 72.000 ha, a semi-detailed soil survey has been carried out on the scale of 1:50.000. The work started in 1991 and was concluded in 1993. At the moment the redaction of the report is being concluded. The standard survey was executed with one observation every cm2 on the map. 2.881 Observations have been carried out, of which89 profiles. Specially prepared forms for the data computerizing have been used for the soil descriptions. The data concerning the description of all the observations have been digitized in a data-base prepared by the Region of Lombardy.
The Soil Taxonomy Classification System (4, 5) has been used for the soil classification, as far as the taxonomic level of the family phases.
Standard laboratory analyses have been carried out on 80 % of the soil profiles.
It has been possible to trace historical maps, which regard the entire area of study. These maps have given precious information on the structure of the zone before the increase of the irrigation water availability and the evolution of the agricultural mechanization greatly changed it.

RESULTS AND DISCUSSION

The area of study (72.498 ha) regards the south-western part of the province of Pavia. It has a population of 60.673 inhabitants (in 1981), distributed over 40 communes (3); there are no great urban centres. It is a lowland zone, mostly of agricultural scope: about 92 % of the agricultural area is cultivated with cereals, mostly rice and in minor degree mais (6). The zone takes part of the extensive traditional area of the Italian rice cultivation which occurs in the provinces of Pavia in Lombardy, and Novara and Vercelli in Piedmont.
In the evolution story of the Lomellinian soils the human activity represents a factor of primary importance: the enormous diffusion of the rice cultivation has brought about the re- modelling of large areas and the drastic change of their moisture regime, especially in spring and summer time.
Particularly two elements are the reason for this situation: the abundance of irrigation water and the technical development of the agricultural mechanization.
If the natural water resources of some parts of the Lomellinian territory already permitted the introduction of the flooded rice cultivation in the 15th century, it is only the accomplishment of a great work, the Cavour Channel (finished in 1866) and it's branches, that the water availability has grown enormously. It is thus that practically everywhere rice cultivation has become possible.
Through calculation the irrigated surface area in Lomellina has increased with 100 % already in 1882 (1), due to the realisation of the Cavour Channel.

The other aspect which has allowed the expansion of the rice cultivation is realized by the elevated degree of mechanization which the farms have reached. Basically, there are three types of tillage operations connected with the puddled rice culture:
1) The levelling and lowering of large areas to create rice "chambers" (single plots separated by small dykes for the water control). The ground movements can already be substantial in the case of simple levelling, in which areas are being put together and the pre-existing morphology has been modified. They become of considerable magnitude, though, in the case of surface lowering. These movements consist in expensive interventions to recuperate land for the rice culture. For example, summit areas not suitable for this cultivation are dismantled and enormous quantities of earth (mostly sandy materials) are thus removed, used elsewhere as inert matter. In this way the ground level of the land can be lowered in the order of 50-100 cm or even more. The goal is to render the water operations less costly.

2) The "lasering" of the chamber surface. To avoid product losses and to spare the water, it is necessary to maintain a homogeneous water level within the chambers. From this stems the necessity to have perfectly levelled soil surfaces. The "lasering" consists of a levelling of the land by means of a mechanical hydraulic shovel, which has to be kept at a constant level by a power plant, which receives a laser signal emitted by a mobile station.
3) The compaction of the soils. The "lasering" itself involves a compaction of the soil, but it is mostly through tillage at a constant depth (usually 25-35 cm) that a compact plough layer with a reduced permeability is created. Also during the crop rotations the plough layer usually remains preserved or gets to be as less disturbed as possible.
The diminished permeability of the upper soil horizons obtained, manifests itself also in the winter months. In this period water stagnation occurs in the chambers also during absence of the crop.

The flooding in spring and summer time causes substantial physical and chemical changes in the soils. The cumulative effect of the flooding cycles prolonged in time, can result in significant alterations, reversible as well as permanent, such as to modify the original soil profile. In many Lomellinian soils these changes of the original profile in the upper horizons re-enter in the morphological typology described in the most recent edition of the Keys to Soil Taxonomy (5) under the definition of "anthraquic conditions":
a) "A tilled surface layer" that shows a matrix which indicates conditions connected with saturation and reduction features like a dominant colour with a chroma of 2 or less;
b) "An underlaying slowly permeable layer", the plough layer, also this one with the colour characteristics of the matrix stated in point a. One deals with a compact horizon, lacking in structure and with a very reduced macro-porosity.
c) "A subsurface horizon" showing "redoximorphic features" like "redox depletions or redox concentrations of iron".
In many soils that originally had a good drainage, the redoximorphic features diminish suddenly below these horizons with depth, up to disappearing completely.
In soils more recently introduced to the rice-paddy these caracteristics are less expressed, also if clear signs are noted that indicate their initial formation.
In the ploughed horizon and in the plough layer, during the saturation period and in the period immediately afterwards, intense processes of reduction and oxidation occur which can lead to ferrolysis (2). In particular, features have been noted in the upper horizons of many soils in the rice-fields that can be thus synthesized:
1) In the rise of clay content between the saturated horizons, which contain less clay, and those horizons immediately below. Also the lower cation exchange capacity of the saturated horizon is related in a great deal to this aspect.
2) A lower pH and often a lower base saturation of the exchange complex in the saturated horizons compared to those immediately below.

The expanse of the rice culture has involved large areas characterized by soils that traditionally have a poor vocation for this flooded cultivation, especially the widely diffused soils with a sandy to coarse loamy texture and a high permeability.
The figure shows the total distribution of the areas concerning these soils: in the area of study they amount to a surface of about 28.000 ha, equal to approximately 38% of the area.
In these soils the protective capacity towards the ground wateris greatly limited due to the good or high permeability of the horizons immediately below the plough layer. If to this is added the fact that these soils through their nature need intense fertilization, it is evident that a high environmental risk can be caused by these activities.
The estimation of the protective capacity of the soils is carried out using an interpretative model that uses the following aspects: permeability, depth of the ground water, granulometric class,

chemical modifiers (pH, CEC). These aspects refer to the soil within a depth of 150 cm or to that part of the soil which is above the upper limit of the ground water fluctuation, when this fluctuation occurs at a depth of less than 150 cm. This model brings along the definition of three classes in the protective capacity of the soils: high, moderate, low.
The zones of the grey coloured figure indicate the soils with a low protective capacity caused by their high permeability, with a natural good to rapid drainage; these rappresent the area more recently introduced to rice cultivation. In the remaining zones, white in the figure, many soil-environmental typologies are introduced. According to the described model circa 13.000 ha (18% of the total surface) are characterized by soils with a moderate or high protective capacity, from the view-point of the protective capacity with regard to the ground water. The remaining 30.000 ha (42% of the total surface area) have soils with a low protective capacity.

The realized interpretation will be tested through it's implementation in two deeds of territorial politics scheduled by the Region of Lombardy:
1) the zoning of the regional areas with a high vulnerability to the leaching of nitrates, and the respective management standards, in execution to the CEE rules;
2) The Regional Plan of the Anti-Parasites, with zoning and respective instructions for the areas at high risk for a pesticide mobilization.

CONCLUSION

The semi-detailed soil survey with a scale 1:50.000 can be an effective instrument to determine the areas in which the tillage connected with a specific cultivation can produce great impact on soil and environment. In case of the rice cultivation in Lomellina, which assumes the characteristics of a mono-culture in most of the area, large areas are concerned that already allow significant comparisons on the semi-detailed scale.
From the spotting of the problem, one passes to it's quantification and to the search of alternatives, on the point of view of the improvements of the land management (minor and better uses of fertilization, reduction of the flooding period, etc.), as well as to favour alternative crops with a lower impact in the areas of minor vocation to rice cultivation.

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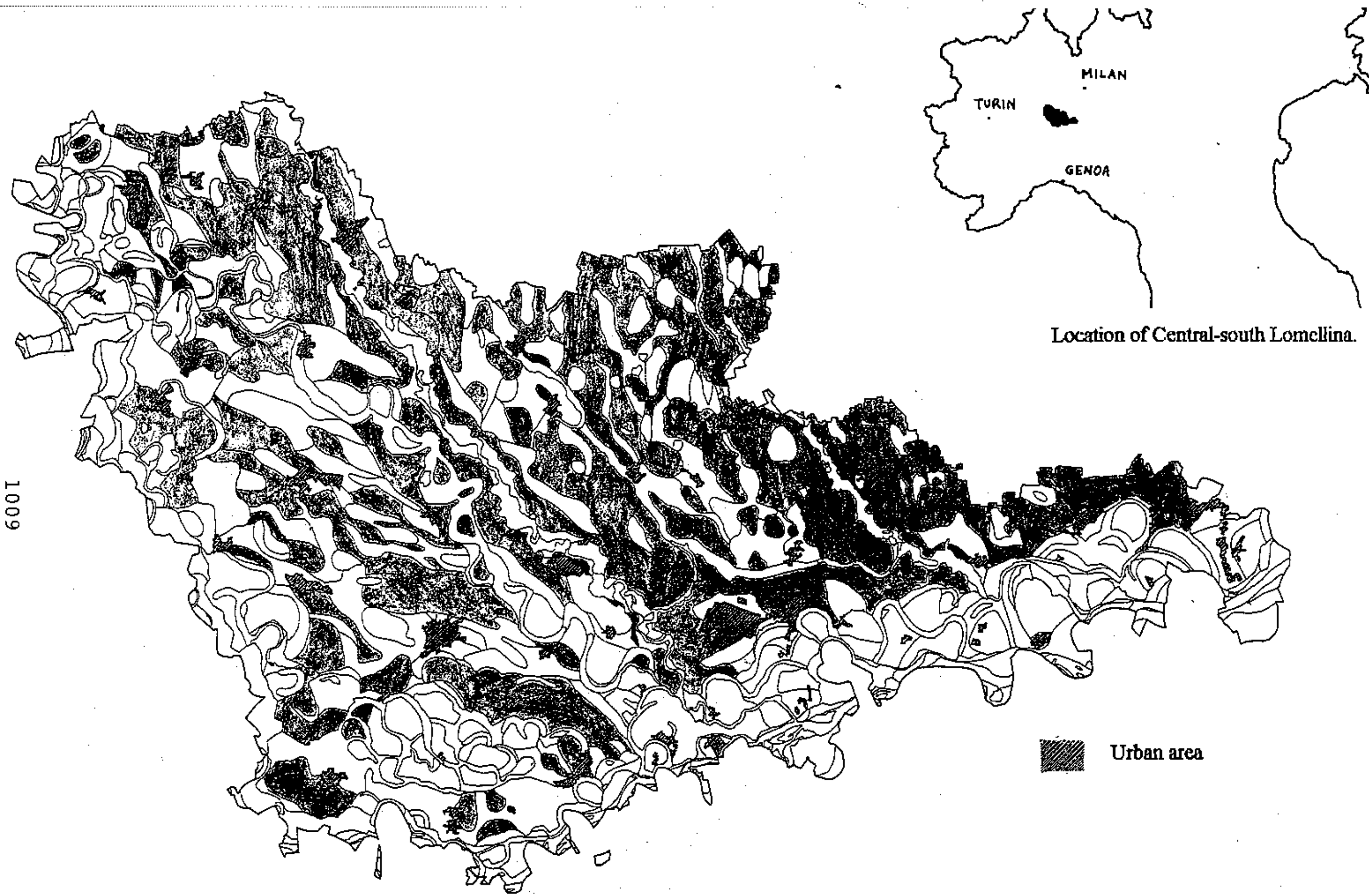

Location of Central-south Lomellina.

Soils with high permeability and internal natural drainage from excessively drained to freely drained in Central-south Lomellina (grey).

A SUSTAINABLE WINTER-LEGUME CONSERVATION TILLAGE SYSTEM FOR MAIZE: EFFECTS ON SOIL QUALITY

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ABSTRACT

The cost of annual seeding is a major constraint to the use of winter cover crops in the USA. A sustainable maize production system for the southern-temperate zone was developed using tropical-adapted maize (*Zea mays* L.). The tropical maize allowed for later planting which enabled a cover crop of crimson clover (*Trifolium incarnatum* L.) to naturally reseed every year in a conservation-tillage system. The system was tested in replicated field studies on a Hartsells sandy loam and a Norfolk loamy sand in Alabama (USA). After using clover for 5 seasons, and 36 to 44 months without tillage, soil physical and chemical properties as affected by winter cover (clover or fallow) and maize N management (0 or 202 kg ha^{-1} applied every year) were determined. The clover system increased soil C and N on the Hartsells soil and K concentrations to the 6-cm depth on both soils. Concentrations of Ca and Mg were increased to the 0-3 cm depth under clover compared to winter fallow. The percentage water-stable aggregates and saturated hydraulic conductivity increased while bulk density was reduced in the clover system. Yields from conservation-tilled tropical maize with reseeding crimson clover are competitive with nonirrigated temperate maize, and our results indicate that such a system can also improve soil chemical and physical properties in a relatively short period.

INTRODUCTION

The benefits of using legumes as green manures and cover crops have been recognized by many cultures since ancient times (1). However, as modern agriculture has become highly capitalized, mechanized and specialized, the use of legume cover crops in agricultural production systems has become almost nonexistent in developed countries. In the southeastern United States, for example, few farmers use winter-annual legume cover crops, even though they are well adapted to the region. This is due in large part to the expense incurred by the necessity to annually reseed the legume cover crop.

Recent research has shown that new maize hybrids, originally bred for the tropics, have excellent grain yield potential in the southern United States, and can be planted late enough to allow a winter legume cover crop to mature seed (2). These tropical hybrids can therefore be grown in a conservation-tillage system with an adapted winter-annual legume without incurring the yearly costs of establishing the winter legume cover crop (3). This should facilitate utilization of winter cover crops and conservation-tillage, both practices which lend themselves to sustainability of the soil resource.

The use of cover crops can improve soil productivity in the long-term as a result of reduced erosion and improved soil chemical and physical properties (1). However, the rate and magnitude of the improvement in soil properties is climate and cropping system dependent. The objectives of the work reported here were to quantify changes in soil chemical and physical properties brought about in a conservation-tillage maize production system with a naturally reseeding crimson clover cover crop after 5 years.

MATERIALS AND METHODS

This study was conducted with two soil types; a Hartsells fine sandy loam (fine-loamy, siliceous, thermic Typic Hapludults) in northeastern Alabama and a Norfolk loamy sand (fine-loamy, siliceous, thermic Typic Kandiudults) in east-central Alabama, USA. In October of 1987 'Tibbee' crimson clover was seeded into specified plots within the experimental area at both locations. A study was conducted to test the N response of six temperate maize hybrids during the following May-August (1988). The experimental design was a strip-split plot design of four replications, using four row plots. Horizontal plots were winter cover, either winter fallow or clover. Vertical plots were N rates ranging from 0 to 269 kg ha^{-1} and sub- or interaction-plots were temperate corn hybrids. The clover plots at both sites were disked and drilled with clover again in October of 1988. In late spring of 1989, a study was imposed on both sites to determine the N response of two tropical-adapted maize hybrids (3). The late planting date (June-July) of the tropical hybrids allowed the clover to mature and naturally reseed every year thereafter (1990, 1991, and 1992). Tropical maize was grown in 1989, 1990, and 1991, using the same design as the temperate maize study begun in 1988. The winter cover and N rate plots remained the same as in the temperate maize study with the exception that the 269 kg ba^{-1} N rate was reduced to 202 kg ha^{-1} beginning with the tropical hybrid-reseeding clover study in 1989.

All plots on both sites were disked prior to planting clover in 1987 and 1988. A unit planter was used to seed maize following in-row subsoiling (40-cm depth) in all years. This operation tilled a narrow (15- to 25-cm wide) area within 76 cm-wide rows. In 1989, because of a severe purple nutsedge (*Cyperus rotundus* L.) infestation, the Norfolk site was disk-plowed (15-cm depth) before planting the tropical maize on 29 July. With this exception, the interrow area was not tilled at either location after October of 1988.

In June of 1992, the interrow area of plots that had been in clover or winter fallow and in which the tropical maize had either 0 or 202 kg N ha^{-1} applied was sampled to determine the impact of winter cover and N fertilization on selected soil properties. All measurements were made from the interrow area between the middle two rows to avoid heavily trafficked areas.

Soil strength was determined with a recording penetrometer following a period of rainfall when the soil was near field capacity. Ten penetrations, taken at random from the interrow area, were made to a depth of 52-cm in 3-cm increments.

Saturated hydraulic conductivity (K_{sat}) was determined from three undisturbed samples per plot using a constant head method (4). Undisturbed cores (6-cm depth) were taken using a 4.8-cm diameter aluminum cylinder 12-cm tall. Before insertion of cylinders, crop residues were removed from the sample area without disturbing the soil surface. Core heights were measured individually in relation to cylinder height to account for variations in micro-relief of the undisturbed samples. The mean of three K_{sat} determinations from each core was used in statistical analysis.

Bulk density was determined from three cores per plot using the core method. Bulk density was determined for the 0- to 3-, 3- to 6- and 6- to 12-cm depths.

Thirty 1.9-cm-diameter cores were taken from each plot and divided into 0- to 3-, 3- to 6- and 6- to 12-cm depth increments. The cores were composited by depth increment and analyzed for C, total N, Ca, K, Mg, P, Cu, Fe, Mn, and Zn. Carbon and N were analyzed using a LECO CHN-600 analyzer (LECO®, Augusta, GA). Calcium, K, Mg, P, Cu, Fe, Mn, and Zn were determined from wet-ashed samples analyzed with an Inductively Coupled Argon Plasma Spectrophotometer (ICAP).

Bulk samples for wet aggregate stability determinations were taken with a spade from the 0- to 3-, 3- to 6- and 6- to 12-cm depths from five locations within each plot. Wet aggregate stability was determined from 1-2-mm air-dried aggregates using the method of Kemper and Rosenau (5).

Data from a single depth were analyzed using ANOVA for a strip plot design and data taken over the three depth increments were analyzed using ANOVA for a strip-split plot design with depth as the sub- or interaction-plots. Means were separated using a protected LSD at the 0.10 level of significance.

RESULTS AND DISCUSSION

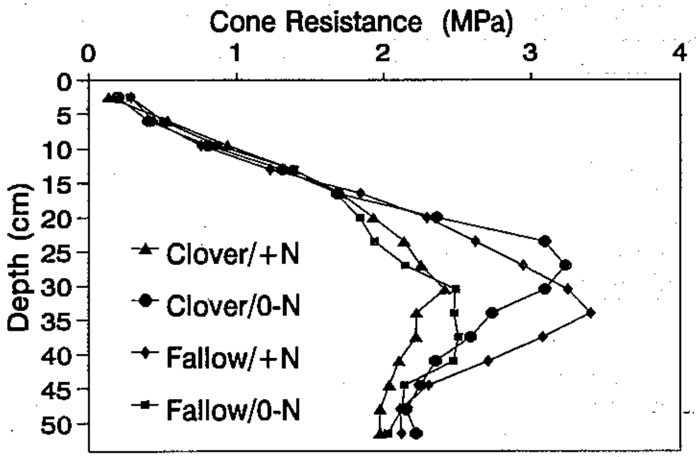
Soil strength

There were no significant effects of winter cover or N rate applied to maize on soil strength of the Hartsells soil. Soil strength of the Norfolk soil was affected by a winter cover X N fertilizer X depth interaction ($P \leq 0.03$, Fig. 1). Soil strength profiles were similar for the clover plots where 202 kg N ha^{-1} was applied and the winter fallow plots where no N fertilizer was applied. Soil strength in the clover plots without N and fallow plots with N was increased between 18- and 40-cm deep in the profile. This soil typically forms a compacted zone between the 15- and 35-cm depth. However, we can offer no explanation as to the interaction effect between winter cover and N fertilizer applied to corn.

Hydraulic conductivity

Saturated hydraulic conductivity of undisturbed cores from the 0- to 6-cm depth increased from 10.7 cm h^{-1} under winter fallow to 36.6 cm h^{-1} under crimson clover ($LSD_{0.10}$= 22.7 cm h^{-1}) on the Hartsells soil. On the coastal plain Norfolk soil K_{sat} increased from 37.2 cm h^{-1} under winter fallow to 79.62 cm h^{-1} under crimson clover ($LSD_{0.10}$=18.8 cm h^{-1}).

Figure 1. Effect of winter cover crop and N fertilizer applied to tropical maize in a conservation-tillage system on soil strength of a Norfolk loamy sand in east-central Alabama.



Bulk density

Bulk density increased with sample depth (Table 1). There was a nonsignificant trend ($P \leq 0.20$) for bulk density to be reduced following clover compared to winter fallow at both locations.

Table 1. Soil bulk density (Mg m^{-3}) by depth of two soils cropped to conservation-tilled tropical maize in Alabama as affected by winter cover crop.

Hartsells soil				Norfolk soil			
Depth (cm)	clover	fallow	mean	Depth (cm)	clover	fallow	mean
0-3	1.27	1.35	1.31	0-3	1.39	1.46	1.43
3-6	1.40	1.52	1.46	3-6	1.49	1.53	1.51
6-12	1.54	1.63	1.59	6-12	1.59	1.65	1.59
$LSD_{0.10}$	ns		0.15	$LSD_{0.10}$	ns		0.13

Aggregate stability

The percentage water-stable aggregates was increased under clover compared to winter fallow on both soils (Table 2). On the Norfolk soil there was a significant winter cover X depth interaction in that the percentage stable aggregates was least in the surface 0- to 3-cm under winter fallow while under clover stable aggregates increased at the soil surface.

Soil carbon and nutrient concentrations

The clover cover crop increased soil C to the 6-cm depth on the Hartsells soil compared to winter fallow but C concentrations were not significantly increased by cover crop on the Norfolk soil (Table 3). Nitrogen applied to maize increased soil C from 6.41 g kg^{-1} to 7.62 g kg^{-1} ($LSD_{0.10}$=0.78 g kg^{-1}) on the Hartsells soil but had no effect on C concentrations on the Norfolk soil.

Table 2. Percentage (%) of water-stable aggregates by depth of two soils cropped to conservation-tilled tropical maize in Alabama as affected by winter cover crop.

Hartsells soil				Norfolk soil			
Depth (cm)	clover	fallow	mean	Depth (cm)	clover	fallow	mean
0-3	55.1	41.2	48.1	0-3	54.7	36.9	45.8
3-6	56.7	46.5	51.6	3-6	48.5	39.8	44.1
6-12	51.5	43.2	47.1	6-12	47.8	41.7	44.5
mean	54.5	43.6			50.4	39.5	
$LSD_{0.10}$ (depth)= 2.7				$LSD_{0.10}$ (depth)= ns			
$LSD_{0.10}$ (cover)= 3.3				$LSD_{0.10}$ (cover)= 2.0			
$LSD_{0.10}$ (cover X depth)= ns				$LSD_{0.10}$ (cover X depth)= 3.2			

The impact of treatments on total N in the two soils was similar to treatment effects on soil C. Crimson clover increased soil N to the 12-cm depth on the Hartsells soil but neither cover crop nor N fertilizer applied to maize affected soil N levels on the coarser-textured coastal plain Norfolk soil (Table 3). Stratification of both soil C and N was apparent on both soils due to the lack of tillage (other than in-row subsoiling at planting) for 36 months on the Norfolk soil and 44 months on the Hartsells soil (Table 3).

Winter cover affected distribution of macronutrients (Ca, Mg, K, and P) with depth on both soils (Table 3). Calcium concentration was higher in the soil surface (0- to 3-cm depth) under clover while under fallow the concentration of Ca increased with depth (to 12-cm) in the profile. Magnesium increased in the 0- to 3-cm depth under clover but remained evenly distributed to 12-cm under fallow at both locations. Potassium was increased to the 6-cm depth at both locations under clover compared to winter fallow. The no-tillage environment resulted in stratification of P within the sampling zone at both locations. On the Hartsells soil, clover increased P in the 0- to 6-cm depth compared to winter fallow. Nitrogen applied to maize generally resulted in reductions of Ca, Mg, K, and P likely as a result of increased yields with N compared to 0-N and consequent plant uptake and removal in grain (data not shown). There were no consistent treatment effects on soil micronutrient (Cu, Fe, Mn, and Zn) concentrations.

CONCLUSIONS

We have previously reported that silage and grain yields of nonirrigated tropical maize hybrids grown in a conservation-tillage winter annual legume system are competitive with nonirrigated temperate maize yields in the southeastern USA (3). Yields of 52 Mg ha^{-1} silage and 6.3 Mg ha^{-1} grain can be obtained with as little as 45 kg fertilizer-N ha^{-1} using this system. The clover cover crop was grown for 5 seasons in this study. However, no-tillage (other than in-row subsoiling) was practiced on the Norfolk soil for only 36 months and on the Hartsells soil for only 44 months. During this relatively short time, significant changes occurred in soil chemical and physical properties under the clover system, especially on the Hartsells soil. The lessened impact of the clover system on the Norfolk soil was likely due to differences in texture as well as one less season with clover under no-tillage than on the Hartsells soil. The improved conditions, i.e., greater soil C, N, P, and K concentrations, more water-stable aggregates, and greater values for K_{sat}, in such a short time are further evidence of the sustainability of this maize production system.

Table 3. Concentrations of carbon and macronutrients by depth of two soils cropped to conservation-tilled tropical maize in Alabama as affected by winter cover crop.

	Hartsells soil											
	Ca		K		Mg		P		C		N	
Depth	clover	fallow	clover	fallow	clover	fallow	clover	fallow	clover	fallow	clover	fallow
-cm-	mg kg⁻¹								g kg⁻¹			
0-3	475	363	125	81	102	84	73	57	10.8	8.2	1.31	0.95
3-6	334	389	85	62	67	81	59	55	7.0	5.8	0.88	0.71
6-12	384	453	57	54	72	88	52	51	5.4	5.0	0.73	0.56
LSD[1]	45		15		7		3		0.91		0.11	
	Norfolk soil											
	Ca		K		Mg		P		C		N	
	clover	fallow	clover	fallow	clover	fallow	clover	fallow	clover	fallow	clover	fallow
	mg kg⁻¹								g kg⁻¹			
0-3	391	268	100	68	78	50	59	56	9.0	8.5	0.74	0.73
3-6	300	276	67	56	58	49	44	50	6.8	6.0	0.51	0.55
6-12	307	320	57	54	53	47	38	45	6.2	5.8	0.46	0.40
LSD[1]	37		7		7		6		ns		ns	

[1]$LSD_{0.10}$ (winter cover X depth)

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THE EFFECT OF RIDGING ON MAIZE YIELD AND TOPSOIL TEMPERATURE AND STRENGTH ON SANDY SOILS

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ABSTRACT

Results of an earlier four years of on-station tillage research had revealed that a tillage system called no-till tied ridging yielded significantly highest maize grain overall in the subhumid agro-ecological zone of Zimbabwe in spite of poorer emergence and crop stands. The poorer emergence and crop stands had been attributed to the observed lower soil water content in the ridges and the hardsetting of the soil in all treatments as the soil became dryer. A field study was therefore initiated to evaluate the soil temperature at sowing depth (approx. 50 mm) and soil strength in the root proliferation zone (approx. 525 mm) with special attention given to permanent ridges. The study, carried out during the 1992-93 growing season, also involved tied ridges of different age, namely 1, 2, and 5 years old.

The results of the analysis of variance showed that the influence of tillage treatment, time of recording, and depth of recording on soil temperature were highly significant. With regards to the ridges, results also showed that the influence of ridge aspect is highly significant. However, no statistically significant differences were found with regards to the age of the ridges. Similarly, there were no statistically significant differences between the different age groups of the ridges with regards to soil strength as established with a cone penetrometer. However, statistically significant differences across treatments could be established with ridges tending to provide least penetration resistance.

INTRODUCTION

Four years (1988-89 to 1991-92) of on-station trials showed that tied ridging, as recommended in Zimbabwe (1), reduces surface runoff (< 1% of seasonal rainfall) and thus sheet erosion (< 0.5 t ha^{-1} $year^{-1}$) to a minimum (2). The treatment also produced highest maize grain yields (4,5 to 5 t ha^{-1} $year^{-1}$) in the subhumid north of Zimbabwe in spite of poorer seedling emergence and lower plant populations at harvest. The poorer emergence and crop stands had been mainly attributed to the observed lower topsoil water contents in the ridges and frequent early-season dry spells (3). Soil temperature measurements and penetrometry tests carried out during the 1991-92 severe drought also showed that tillage had a significant effect on both topsoil temperature and soil mechanical impedance (4). Tied ridging produced the most

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unfavourable topsoil temperature regime in the ridges, yet the most favourable rooting volume.

Because of these opposing features associated with tied ridging, and also because the technique is already being promoted country-wide by the agricultural extension service, a detailed field study was carried out during the 1992-93 rainfall/growing season to further evaluate soil temperature at sowing depth and soil strength within the main rooting zone. Special attention was given to tied ridges involving both newly installed ridges as well as permanent ridges of 2 and 5 years age.

MATERIALS AND METHODS

The study site is located at Domboshawa (17°35'S, 31°10'E) in the subhumid (approx. 800 mm rainfall per year) north of Zimbabwe at an altitude of between 1550 to 1570 m above sea level. Soils are shallow, derived from granite. They feature coarse texture, little inherent fertility, and are frequently subject to transient waterlogging (5).

Four animal-drawn plus one hand-operated tillage systems were tested, namely mouldboard ploughing, ripping into maize residues, ripping into bare ground, no-till tied ridging, and hand hoeing. All ploughing and ripping was to 200-250 mm depth. In the case of tied ridging, ridges were permanent and only re-ridging and re-tying (at 1 m intervals) was practised. All ridges were oriented east-west on a north-facing slope. The crop was planted into the crest of the ridges using a digging hoe (badza). The badza also constituted the only implement employed for the hoeing treatment. All treatments were laid out in completely randomized block designs with either 7 or 11 replications (3).

Maize (*Zea mays* L.) was grown at a density of 44000 plants. Planting was to approximately 50 mm depth for all treatments. For final analysis, grain yields were corrected to a uniform moisture content of 12.5% while stover yields are reported at 0% moisture.

Soil temperature was recorded twice daily (06h00 and 14h00) at two depths (50 and 100 mm) on all five tillage treatments plus on bare plots (kept free of weeds through regular herbicide application). All temperature measurements, employing hand-held digital thermometers with needle sensors, commenced from the day of planting (24 November 1992) and lasted until 100 % silk emergence (10 February 1993). Recording was restricted to two replications per treatment. Readings were taken at different points each day within the maize rows and on the ridge flanks and furrows respectively. It is important to note that two thermometers were used; one involving all 5-years old treatments while at the same time a second operator took readings across the three age groups of the ridges. Although the two sets produced the same relative results, the absolute values varied up to 2°C.

Soil strength was estimated with a hand-held Bush penetrometer using a 12,83 mm diameter cone. Readings were taken on 27 November 1992 (i.e. 3 days after planting), on 10 February 1993 (i.e. at 100 % silk emergence), and on 22 April 1993 (i.e. at harvesting). Recording was restricted to three replications per treatment from which a total of eighteen penetration readings were taken at random; nine within the crop rows and nine between crop rows. In addition, soil strength was recorded weekly across the three age groups of the ridge-furrow systems for the same two-months period for which soil temperature readings were taken. Maximum penetration depth was 525 mm. Unlike during the previous 1991-92 season (4), measurements were not terminated when the overload signal (set at 50 kg or 3810 kPa) bleeped but instead the cone was pushed through to the maximum penetration depth or until the operator's maximum strength in pushing was reached (approx. 80 kg or 6096 kPa). This heavy use required regular checking of the equipment's calibration, which was not affected. The overload signal was disregarded in order to avoid, or at least minimise, the number of censored observations (6).

RESULTS AND DISCUSSION

Crop production

During the 1992-93 season (which received a total rainfall of 797 mm), maize planted on tied ridges grew faster and significantly taller than the crops on the other treatments. This was particularly so during the early part of the season which experienced abundant rainfall. As in other average or above average rainfall years, maize grown on ridges benefitted from improved rooting volume (3) and highest root length density (7). Consequently, maize grain and stover yields for tied ridging were significantly higher than for the other treatments, except for grain yield for hand hoeing (Table 1).

Tillage systems	Grain yield	Stover yield
Tied ridging	6.6^{a}	4.3^{a}
Hand hoeing	6.3^{a}	3.1^{b}
Convent. tillage	5.1^{b}	3.1^{b}
Clean ripping	4.8^{b}	2.8^{b}
Mulch ripping	4.3^{b}	3.0^{b}

TABLE 1: Effect of tillage treatment on maize grain and stover yields (t ha^{-1}) during the 1992-93 season at Domboshawa, Zimbabwe. Means within a column followed by the same superscript do not differ significantly at $P < 0.05$.

Soil temperature

Soil temperature strongly influences crop production since it affects germination, emergence, early root development, and nutrient uptake (8). Various studies have shown that the optimum root temperature for maize seedlings is 30°C with little diurnal fluctuations (9, 10).

As a result of fairly well distributed rainfall and frequent overcast weather conditions, average topsoil temperatures for the two month measuring period, and even for the afternoon (14h00), remained below the optimal 30°C (Table 2). They were also considerably lower (up to 8°C) than during the previous 1991-92 drought year (4). As could be expected, overall as well as afternoon topsoil temperatures were significantly highest on the bare field plots and significantly lowest under mulch. Similarly, early morning topsoil temperatures in the furrow bottoms of the ridge-till system were significantly highest except for mulch ripping at 50 mm depth. However, even during the early afternoon, furrows featured topsoil temperatures as high as all the other cropped treatments. This, again, was in stark contrast to the previous drought season when topsoil temperatures in the furrow bottoms had been significantly lowest (4). The relatively high topsoil temperatures in the furrow bottoms in 1992-93 are also reflected by the overall average temperature of 21.9°C which was significantly higher than for all other treatments except the bare plots (Table 2). No statistically significant differences were found with regards to the age of the ridges (1, 2, and 5 years old).

Across the ridge-furrow micro-relief where the ridge tops, flanks, and furrows receive different quantities of solar radiation during the day (11), temperatures at 50 mm depth in the ridge flanks exposed to the south were significantly highest in the afternoon (14h00) while the overall average temperature at this position was as high as in the furrow bottom (Table 3). It is assumed that this asymmetrical distribution of soil temperature across the ridge is mirrored by an equally asymmetrical soil water distribution (12).

The observed high topsoil temperatures in the southern flank of the ridges as compared to the northern flank could be expected since temperatures were recorded during the period of the year when the sun was not far from or at its furthest south; the south side of the ridges running in an east-west direction thus received more solar radiation. The ridge tops, which had experienced significantly lowest early morning and significantly highest afternoon topsoil temperatures during the 1991-92 drought season (topsoil temperatures in the south flank had not been recorded in 1991-92), again featured the lowest early morning but not the highest afternoon topsoil temperatures in 1992-93 (Tables 2, 3). Obviously, the frequent rains, in conjunction with the high degree of cloudiness, prevented ridges from drying out too much thus maintaining afternoon topsoil temperatures at levels only slightly higher than for the other cropped treatments. Radke *et al.* (13), in a controlled laboratory simulation of soil temperature and soil water patterns under a soil ridge, showed that soil temperatures increased most rapidly where the soil was driest and evaporation low, namely at the top of the ridges or on the south slope.

Tillage systems and/or topography	50 mm		100 mm		Overall average temperature
	06h00	14h00	06h00	14h00	
Bare plots	16.2	29.2	16.9	27.8	22.5[a]
Ridge furrow	17.5	26.5	18.5	25.2	21.9[b]
Hand hoeing	16.8	26.6	17.7	25.6	21.7[c]
Clean ripping	16.7	26.4	17.6	25.2	21.5[cd]
Convent. tillage	16.6	26.3	17.4	25.4	21.4[cd]
Ridge N-flank	16.4	26.2	17.1	25.2	21.2[d]
Ridge top	16.0	26.6	16.7	25.7	21.2[d]
Mulch ripping	17.1	24.4	17.8	23.7	20.8[e]
LSD	0.5				

TABLE 2^: Effect of tillage treatment on mean topsoil temperatures (°C) at 50 and 100 mm depth at 06h00 and 14h00 local time as recorded between 24 November 1992 to 12 February 1993 at Domboshawa, Zimbabwe. $R^2 = 0.97$, CV = 5.0.

Topographic position in ridge system	50 mm		100 mm		Overall average temperature
	06h00	14h00	06h00	14h00	
Furrow bottom	19.6	28.1	20.4	26.5	23.6[a]
South flank	18.5	29.2	19.4	27.4	23.6[a]
North flank	18.4	27.7	19.3	26.4	23.0[b]
Ridge top	17.9	28.4	18.8	27.0	23.0[b]
LSD	0.5				

TABLE 3^: Mean topsoil temperatures (°C) in east-west oriented ridge-furrow systems at 50 and 100 mm depth at 06h00 and 14h00 local time. Figures are means across all three age groups of the ridge-furrow system over a period of two months at Domboshawa, Zimbabwe. $R^2 = 0.97$, CV = 4.1.

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^Means within a column followed by the same superscript do not differ significantly at P < 0.05. The least significant difference (LSD) value applies to across-treatment comparisons within the same column and to within-treatment comparisons taken at the same time.

Soil strength

Cone penetration resistance was employed to evaluate soil strength or mechanical impedance to maize root growth. Various studies have shown that soil strength increases (thus restricting further root growth) with decreasing soil water matric potential or increasing suction (14, 15). In sandy soils this causes an increase in soil internal friction (16). Other research also showed that root growth essentially terminates in soil where probe resistance exceeds 2000 kPa (17, 18).

This critical resistance was generally reached close to (either slightly above or below) maximum cultivation depth (200-250 mm) in ploughed, ripped, and hoed field plots, and at 300-350 mm depth in ridged field plots. In most cases the observed differences were, however, statistically not significant (at $P < 0.05$). Exceptions were the ridge furrows and either hoed or cleanly ripped field plots in the middle of the season when soil water content was furthest below field capacity. While, on 27 November 1992, soil water content was more or less at field capacity, by 10 February 1993 it had dropped by 5% below field capacity at 450 mm depth and by 40% at 150 mm depth for all treatments where cultivation was on flat ground. In tied ridged soil, soil water content was 50% below field capacity throughout the top 450 mm in the ridges on 10 February 1993. On 22 April 1993, soil water content was 5-20% below field capacity in flat ground and 15-35% in the ridges.

Although having been in place for five consecutive years, ridges tended to have the lowest soil strength over the top 250 mm of the soil (= maximum depth of cultivation) while hoed field plots tended to have the significantly highest (Table 4). The latter is to be expected since hoeing only tills the soil to a maximum depth of about 100 mm; hence soil strength in hoed plots increases practically linearly down to approximately 250 mm soil depth (4). It is important to note, that this depth level not only coincides with the maximum depth of cultivation in ploughed and ripped field plots but also with the presence of an apparently natural subsoil pan (7). This pan may have been caused by the precipitation of iron-manganese concretions at this upper limit of the seasonally fluctuating water table (5).

It was anticipated that permanent soil ridges would display a significantly higher degree of consolidation than newly ridged soil. Contrary to expectation, however, there were no statistically significant differences in soil strength between the three age groups of ridges (1, 2, and 5 years old). This growth-favourable preservation of relatively loose soil in the ridges over many years in otherwise compact and consolidated soil may be related to more pronounced drying and wetting cycles in the ridges as well as to minimal lateral stress (13).

CONCLUSION

Maize yields, topsoil temperature in the seed zone, and soil strength in the root zone were all affected by tillage treatment on the sandy soils at Domboshawa. Tied ridging had best crop stands and highest yields. Unlike during the previous drought year, topsoil temperatures in the top of the ridges did not rise to significantly higher levels than for the other treatments. Soil strength in the ridges tended to be lower than for the other treatments which was conducive to maize root proliferation. This manifested itself in double the root length density for tied ridging as compared to ploughing.

Because ridging improved rooting volume and drainage by raising the seedbed above the subsoil pan, and by helping alleviating high soil strength, it appears to be the most suited tillage technique for naturally highly compact sandy soils with a seasonally fluctuating shallow water table such as found at Domboshawa in Zimbabwe.

Tillage techniques	Ridge/in-row measurements to 250 mm soil depth	Ridge/in-row measurements to 525 mm soil depth	Furrow/between-rows measurements to 250 mm soil depth	Furrow/between-rows measurements to 525 mm soil depth
	27 November 1992 (3 DAP)			
Tied ridging	480^{c}	1661	1455^{a}	2736
Conv. tillage	541^{bc}	1699	503^{c}	1608
Mulch ripping	884^{abc}	1867	747^{bc}	1737
Clean ripping	930^{ab}	1646	953^{abc}	2210
Hand hoeing	1265^{a}	1943	1303^{ab}	2507
	10 February 1993 (78 DAP)			
Tied ridging	1090^{b}	2179	2469^{a}	3239
Conv. tillage	1074^{b}	2149	1143^{d}	2240
Mulch ripping	1638^{a}	2797	1455^{cd}	2515
Clean ripping	1494^{ab}	2423	1768^{bc}	2842
Hand hoeing	1958^{a}	2903	1951^{b}	2819
	22 April 1992 (149 DAP)			
Tied ridging	754	1669	1958^{a}	3117
Conv. tillage	907	2377	953^{c}	2484
Mulch ripping	1067	2256	1135^{bc}	2301
Clean ripping	1166	2164	1562^{ab}	2362
Hand hoeing	1273	2431	1692^{ab}	2652

TABLE 4: Mean profile soil strengths (kPa) for five tillage systems during the 1992-93 rainfall/growing season at Domboshawa, Zimbabwe. Means within a column followed by the same superscript do not differ significantly at $P < 0.05$. DAP = days after planting.

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EFFECT OF ZERO AND MANUAL TILLAGE ON SOIL PROPERTIES AND OKRA

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ABSTRACT

Zero tillage, hoeing, ridge and heap treatments were tried on two okra crops in 1992. The values of soil moisture content, temperature, nutrient content, okra leaf nutrient content and pod yield were determined. Zero tillage produced lower soil temperature, higher soil moisture content, N, organic matter, Ca and Mg contents than any of the tillage treatments. Zero tillage also produced higher values of leaf P, Ca and Mg, and significantly higher okra pod yield than any tillage treatment.

INTRODUCTION

Research on tillage requirement of okra (Abelmoschus esculentus) has received little attention, whereas okra is an important tropical vegetable grown for its pod. The traditional manual tillage practices include making of heaps, ridges and hoeing of soil. Whereas there is need to integrate soil conserving zero tillage into cropping practices of humid tropical regions, few studies exist on the role of zero tillage in okra production. Azoegwu (1) compared the effect of zero tillage and conventional tillage with or without mulch on soil physical properties and okra yield. It was found that conventional tillage with mulch gave the highest yield. The question to be answered by this work is how does zero tillage compare with manual tillage practices in their effect on soil properties, okra composition and yield.

MATERIALS AND METHODS

The experiment was performed on two crops of okra in 1992 at Akure (7° 5'N, 5° 10'E) on an ultisol with 64.5 % sand, 12.2 % silt and 24.3 clay in 0 to 15 cm depth.

Soil tillage treatments

The site was manually cleared. In April 1992 four tillage methods, (1) Zero-tillage in which grammoxone was sprayed at 3.5 L/ha, (2) Manual tillage with hoe, (3) Ridge (manual) and (4) Heap (manual) were established on a land slope of 3 %. Treatments were replicated three times in a completely randomized block design. Seeds of the 42-day flowering okra variety Clemson, were planted on plant per stand at 90x90 cm in each of 10x10 m plots. The second crop was planted in July 1992 in the same plots after the treatments were repeated.

Soil physical properties

Soil moisture content and temperature were determined for each crop and plot at different dates. Core samples collected at 5 to 15 cm depth were used in the evaluation of bulk density and volumetric moisture content after placement of samples in an oven for 24 h at 100° C. Four core samples were collected from each of manually cleared, hoed, ridge and heaped soil each sampling time. Soil temperature was evaluated with the use of a soil thermometer inserted to 10 cm, and there were 12 readings to each treatment at each sampling.

Leaf analysis

Before the start of harvest of the second crop, topmost leaf samples were removed from each plot, dried in oven at 80° C and ground in a Wiley mill before digestion with nitric-perchloric-sulphuric acid mixture. P was determined colorimetrically, and K, Mg and Ca by flame photometry.

Soil chemical analysis

Air-dried and 2mm-sieved soil samples collected from each plot at 0 to 15 cm depth were chemically analysed. Organic carbon (dichromate oxidation), total N (Kjeklahl) and Bray-1P were determined. Exchangeable K, Ca and Mg were extracted using ammonium acetate and determined by atomic absorption spectrophotometer.

Yield determination

Harvest of pods started 48 days after planting. Values of number and weight of pods on the basis of 20 randomly selected plants per plot were recorded and accumulated.

RESULTS AND DISCUSSION

Soil properties

Zero tillage produced the highest soil moisture content (Table 1). The mean values of soil moisture content for hoeing, ridge and heap were not significantly different. Accordingly zero tillage tended to have the least soil temperature (Table 2). The highest moistrue content and relatively low soil temperature recorded for zero tillage are attributable to organic mulch, (Table 3). Zero tillage also had the highest value of soil N, Ca and Mg and had had relatively high P value (Table 3). Heap produced least values of soil N, P and Mg. The highest soil nutrient content recorded for zero tillage is consistent with its relatively high soil organic matter content.

Okra yield and nutrient content

Okra plant on zero tillage soil also had the higbest values of leaf P, Ca and Mg (Table 4). Zero tillage also produced the best yield of late okra and highest number of pods (Table 5). The best performance of okra on zero tillage soil is consistent with its relatively high soil moisture, N, Ca and Mg contents. Heap that had least values of soil N, Ca and Mg had least yield. Fresh okra pod contains approximately 86.1 % water, 2.2 % protein (which is N-dependent) and 0.8 % ash (mainly cations).

Table 1 Effect of tillage treatment on soil volumetric moisture content (%).

Tillage Treatment	Date 12/5	12/6	2/8	5/9	Mean
Zero tillage	14.5	20.8	14.5	7.7	14.4
Hoe	9.3	4.1	4.8	1.8	5.0
Ridge	5.1	3.5	3.0	2.1	3.4
Heap	6.6	4.8	4.3	2.2	4.5

LSD (0.05) for mean = 4.7

Table 2 Effect of tillage treatment on soil temperature (°C)

Tillage Treatment	Date 12/5	15/6	14/7	18/8	Mean
Zero tillage	26.3	20.0	28.4	27.2	27.7
Hoe	30.7	30.9	31.5	32.2	31.3
Ridge	31.4	31.0	31.0	33.6	31.8
Heap	31.1	28.9	30.4	30.1	30.1

LSD (0.05) for mean = n.s.

Table 3 Effect of tillage treatment on soil nutrient content

Tillage Treatment	O.M %	N %	P ppm	K m.e/100g	Ca m.e/100g	Mg m.e/100g
Zero tillage	3.1	0.24	8.1	0.17	12.3	2.7
Hoe	2.2	0.19	11.3	0.18	5.1	1.4
Ridge	1.5	0.11	4.1	0.13	7.3	1.3
Heap	1.3	0.08	3.3	0.15	6.1	0.8
LSD(0.05)	0.82	0.120	5.43	0.033	4.73	1.62

Table 4 Effect of tillage treatment on okra leaf composition

Tillage Treatment	P %	K %	Ca %	Mg %
Zero tillage	0.33	5.8	10.3	4.6
Hoe	0.27	6.0	7.5	3.0
Ridge	0.24	7.0	8.9	3.2
Heap	0.20	5.7	7.7	3.2
LSD(0.05)	0.084	1.74	1.32	0.97

Table 5 Effect of tillage treatment on pod yield of early (E) and late (L) okra (per plant)

Tillage	No of pods		Pod weight (g)	
Treatment	E	L	E	L
Zero tillage	16	13	300.8	207.9
Hoe	14	12	294.3	169.6
Ridge	15	11	312.6	160.4
Heap	12	9	302.7	153.0
LSD(0.05)	3.8	3.5	24.74	47.13

CONCLUSION

1. Zero tillage was more suitable for okra production when compared witb manual tillage practices.

2. Manual tillage practices reduced soil fertility when compared with zero tillage.

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SOIL CONDITIONS UNDER CONVENTIONAL AND ZERO TILLAGE SYSTEMS WITH AND WITHOUT MULCH AND FERTILIZERS

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ABSTRACT

The effect of tillage, mulch and fertilizers on some properties of an Alfisol in the southern Guinea savanna region of Nigeria was studied. Two tillage treatments - conventional and zero tillage systems, two mulch rates - 0 and 5 t ha^{-1} with and without fertilizers arranged in a randomized complete block design with four replications were compared. Bulk density and penetrometer resistance taken at 4 weeks after planting (WAP) were higher in the surface soil (0-10 cm) of zero tillage compared with the conventional tillage. The differences disappeared at 12 WAP. Mulching significantly reduced the bulk and penetrometer resistance of the surface soil at 4 WAP. The amounts of organic carbon, P, Ca, Mg and K were higher in the top soil of zero tillage than conventional tillage and also in mulch than unmulched plots. Fertilizer application siginificantly affected top soil contents of Ca, K and P in both seasons. The subsoil content of Bray No. 1 p was significantly higher in conventional than in zero tillage plots and in fertilized than unfertilized plots. Soil pH declined slightly after the two years of cropping. Values were lower in zero than in conventional tillage plots and in fertilizer than unfertilized plots. Although the differences obtained in this study are small, probably due to the relatively short duration of the experiment, they are of interest principally as early indicators of the possible long-term trend in these soils especially under intensive cultivation.

INTRODUCTION

The need for investigating the potential for zero/minimum tillage in modern farming in Nigeria arises from the fact that the numbers of tractors and animals available for cultivation are very limited and it is essential that they are used efficiently and hence that unnecessary cultivators are avoided. The second point, which, may even be a stronger reason is the urgent need to check soil erosion which often accompanied intensive cultivation.

A shift from the conventional methods of land preparation (i.e. disc ploughing and harrowing and manual labour with local implements) to minimum/zero tillage is likely to cause some changes in some soil physical and chemical properties and nutrient availability. A great volume of research in this area has been carried out but mainly in the temperate regions where the technique was first used as an attractive alternative. No difference in soil bulk density under zero tillage as compared with conventional tillage systems have been reported by several workers (1, 2, 3, 4 and 5) reported that under zero tillage systems, the surface soil pH decreased rapidly. Lal (7) showed that organic matter, CEC, total N and extractable Ca, Mg and K were higher for zero tillage than conventional tillage. Increased content of organic matter and plant nutrients in zero tillage plots have been reported (8, 9 and 10). Some of these benefits of zero tillage

have been largely attributed to mulch and surface application of fertilizers.
There is no information on this subject for the southern guinea savanna zone of Nigeria. Lal (11 and 12) reported studies in the rainforest zone while (13), (10) reported on work done in the northern guimea savanna zone. Considering the soil and crop specificity nature of this subject, it may be misleading to carry information from one ecological zone to another. Furthermore, the wide range of soil, climate and management practices with which agriculture must contend with, even in the same ecological zone would hardly suggest this.

The study, therefore, investigated the effect of conventional and zero tillage systems with and without mulch and fertilizer on some soil properties of an Alfisol in the southern guinea savanna zone of Nigeria.

MATERIALS AND METHODS

The experiment was established at Mokwa (Lat. 09° 18'N and Long. 05° 04'E) on the research farm of the Agricultural Research Station, Institute for Agricultural Research, Ahmadu Bello University, Zaria. The area has a mean annual rainfall of 1055 mm. The soil is classified as Alfisol Paleustalfs underlain by the Nupe sandstone. As is characteristics of most savanna soils, it is of low inherent fertility and the low clay content is predominantly kaolinitic. Some soil properties prior to the establishment of the experiment are shown in Table 1. The site was under fallow for two years after being used for some herbicide trials.

Table 1. Some selected soil properties of the experimental site

Parameter	Soil depth (cm)	
	0 - 15	15 - 30
Organic C (g kg^{-1})	5.9	3.5
Total N (g kg^{-1})	0.37	0.35
pH (1:1 soil water)	6.4	5.6
Bray P - 1 (mg kg^{-1})	11.9	4.9
Exch. Ca (cmol kg^{-1})	2.50	1.93
Exch. Mg (cmol kg^{-1})	0.69	0.35
Exch. K (cmol kg^{-1})	0.12	0.08
Sand (g kg^{-1})	820	760
Silt (g kg^{-1})	120	160
Clay (g kg^{-1})	60	80

The treatments were two tillage systems (zero and conventional tillage); 2 mulch rates (0 and 5 t ha^{-1}) an 2 fertilizer rates (with and without fertilizer rates (with and without fertilizer). All possible combinations of these treatments were arranged in a randomized complete block design and replicated four times. In the zero tillage system, the plots were sprayed with 2.5 kg ha^{-1} paraquat (1-1 dimethyl 4, 4-4-bipyridynum) before planting while the conventional tillage plots were disc ploughed and harrowed twice. The fertilizer treatment was N, P, K fertilizers applied at the rates of 120 kg N ha^{-1} as Calcium Ammonium Nitrate (CAN) 25 kg P ha^{-1} as single super phosphate (SSP) and 50 kg K ha^{-1} as muriate of potash (KCl). All the SSP and KCl were mixed with one third of CAN and applied to appropriate plots by surface broadcast before planting. The fertilizers were incorporated in the conventional tillage plots with a disc harrow. At four weeks after planting, the remaining two thirds of CAN was applied by hand application. Maize (var. TZPB) was planted at 75 cm between and 25 cm within row spacing. This was thinned to one plant per hill about 10 days after planting. The residues were evenly spread out between rows of appropriate plots immediately after planting.

Prior to the establishment of the experiment soil samples were collected from the field at 0-15 and 15-30 cm depth intervals. At the end of each season soil samples were taken from each plot at similar depth intervals. The samples were air-dried, gently crushed and passed through a 2-mm sieve. Subsamples were taken for some analysis. Soil pH was determined with a glass-electrode pH meter using a 1:1 soil: water suspension after equilibration. Organic carbon was determined by (15). Phosphorus was determined by the Bary No. 1 method as described by (16). Exchangeable cations were extracted by the neutral N ammonium acetate extraction method as described by (16). Exchangeable Ca and Mg were determined by the atomic absorption spectro scopy while K was by the flame photometer. Total N was determined by the macrokjeldahl technique described by (17). Particle size distribution was estimated by the hydrometer method as described by (18).

Soil compaction was measured by a pocket penetrometer CL-700 manufactured by Soil Test Inc. Readings were made at the surface at 4 and 12 weeks after planting. Fifteen readings were taken per plot and average calculated.
Soil bulk density measurements were taken at the same time as the compaction measurement at 0-10 and 10-20 cm depth intervals in each plot with a sampling ring, 5.5 m in diameter and 3.0 cm deep. The samples were oven dried at 105°C, weighed and bulk density calculated.

RESULTS AND DISCUSSION

Bulk density and penetrometer resistance

The effect of tillage, mulch and fertilizer on soil bulk density measured at 4 and 12 WAP is shown in Table 2. Generally, bulk density increased with depth under all treatments but the change was more pronounced under conventional than zero tillage irrespective of mulch and fertilizer treatments. The bulk density of the surface soil at 4 WAP in zero tillage was significantly higher than in conventional tillage. This is expected because of negligible disturbance of the soil under zero tillage. At the lower depth (10-20 cm) there was little change between the two tillage treatments. The differences between the two tillage treatments disappeared at 12 WAP. Nangju (19) reported similar results. This result indicates that in these soils although tillage loosens the soil it soon returns to a state similar to that which had not been tilled probably because of subsequent recompaction of the plough layer. The lower bulk density in mulched as compared to the unmulched plots may be expected. Compaction due to rain drop is generally reduced by mulching hence the reduction of bulk density. In 1983, between 4 and 12 WAP, bulk density in the 0-10 cm depth increased by 0.11 and 0.04 g cm^{-3} under conventional and

Table 2. Effect of tillage, mulch and fertilizer on bulk density (g cm^{-3})

Treatment	1983								1984							
	Fert				No Fert				Fert				No Fert			
	4 WAP		12 WAP		4 WAP		12 WAP		4 WAP		12 WAP		4 WAP		12 WAP	
	0-10	10-20	0-10	10-20	0-10	10-20	0-10	10-20	0-10	10-20	0-10	10-20	0-10	10-20	0-10	10-20
M^+ CT	1.33	1.44	1.41	1.49	1.31	1.46	1.45	1.46	1.34	1.45	1.43	1.49	1.34	1.49	1.4	1.4
M^+ ZT	1.41	1.47	1.43	1.48	1.43	1.46	1.47	1.44	1.43	1.48	1.42	1.46	1.44	1.49	2	1.4
M^- CT	1.34	1.45	1.42	1.47	1.37	1.47	1.49	1.50	1.35	1.47	1.46	1.48	1.37	1.47	1.4	1.4
M^- ZT	1.42	1.48	1.48	1.45	1.43	1.46	1.47	1.47	1.43	1.46	1.45	1.51	1.44	1.50	2	1.47
															1.4	
															5	
															1.4	
															7	
LSD (0.05)																
Fertilizer (F)	NS	NS	NS	NS					NS	NS	NS	NS				
Mulch (M)	0.02	NS	NS	NS					0.014	NS	NS	NS				
Tillage (T)	0.02	NS	NS	NS					0.014	NS	NS	NS				
M x F	NS	NS	NS	NS					NS	NS	NS	NS				
F x T	NS	NS	NS	NS					NS	NS	NS	NS				
M x F x T	NS	NS	NS	0.03					NS	NS	NS	0.03				

Table 3. Effect of tillage, mulch and fertilizer on penitrometer resistance (kg cm^{-2})

Treatment	1983				1984			
	Fert		No Fert		Fert		No Fert	
	4 WAP	12 WAP	4 WAP	12 WAP	4 WAP	12 WAP	4 WAP	12 WAP
M^+ CT	0.74	2.16	0.77	2.06	0.64	2.57	0.80	2.40
M^+ ZT	1.97	2.33	1.96	2.42	2.01	2.53	2.28	2.60
M^- CT	1.02	2.50	0.78	2.16	1.07	2.75	0.74	2.71
M^- ZT	1.95	2.52	2.17	2.74	2.25	2.52	2.37	2.62
LSD (0.05)								
Fertilizer	NS	NS			NS	NS		
Mulch	0.09	NS			NS	NS		
Tillage	0.09	NS			0.14	NS		
M x F	NS	NS			0.19	NS		
F x T	0.13	NS			0.19	NS		
M x F x T	0.18	NS			NS	NS		

zero tillage respectively and by 0.06 and 0.07 g cm^{-3} for mulched and unmulched treatments respectively. In 1984, the corresponding values for the same depth and treatments were 0.09 and 0.04 g cm^{-3} respectively and 0.04 and 0.06 g cm^{-3} respectively. These differences may probably be due to the beating action of raindrops. For an Alfisol of the rainforest soils of western Nigeria, (20) observed an increase in bulk density of 0.0025 g cm^{-3} for every 2.5 mm precipitation during the growing season.

In both seasons, at 4 WAP, the effect of mulch, tillage and the interactions (Fertilizer x tillage and mulch x fertilizer x tillage) on penetrometer resistance was significant. Fertilizer generally did not affect penetrometer resistance (Table 3). The less penetrometer resistance on mulched as compared to unmulched plots may be due to reduction in surface crust by mulching. Mulching is reported to be particularly effective in preventing surface crusting (21). These effects of mulch and tillage on penetrometer resistance are similar to what was obtained with bulk density and it further confirms that some form of tillage may be necessary for continuous cropping on these soils especially when all operations (planting, weeding and harvesting) are done manually. The human traffic involved in these operations may worsen compaction problem over extended period of time.

Soil chemical properties

The influence of tillage, mulch and fertilizer treatments on top and sub soil chemical properties are shown in Tables 4 and 5. For both seasons, tillage, mulch and the interactions effects on all parameters in the surface soil were not significant (Table 4). The organic carbon content was slightly higher in zero than in conventional tillage plots. Similar results have been reported (19 and 22). Root activity in zero tillage is commonly higher in the surface soil (23). This could contribute to higher organic C in zero tillage. The presence of dead weedy species in zero tillage may also contribute to higher organic C. In 1984, sub soil organic carbon content was significantly higher in conventional than in zero tillage plots. This may be due to the incorporation of thrash during land preparation.

Soil pH at both depths were generally lower in zero than in conventional tillage. In the top soil, this was significant only in 1983. Though fertilizer treatment did not significantly affect soil pH, values at both depths were generally lower in the fertilized plots. This may probably be due to the continuous application of chemical fertilizers especially N. There was a slight decline in soil pH values after the second season's cropping. For the top soil, the range was between 0.3 to 0.5 pH units. This change was less for unfertilized plots (0.3) and highest for the zero tillage plots (0.5).

The exchangeable Ca and K in the top soil were significantly higher in the fertilized than unfertilized plots. Values were slightly higher in zero than in conventional tillage plots. Mulched plots also showed higher values of these elements than unmulched plots. The Mg contents of both the top and subsoils were not significantly affected by all treatments. Values in the topsoil were, however, higher in zero tillage and mulched plots.

In both years, fertilizer application significantly increased Bray-1-P contents at both soil depths. Although the effects of mulch and tillage treatments were not significant, values were slightly higher in zero tillage and mulched plots. Sub soil P content was

Table 4. Effect of tillage, mulch and fertilizer on top soil (0-15 cm) chemical properties

Treatment	1983												1984											
	Fert						No Fert						Fert						Fert					
	Ca	Mg cmol kg^{-1}	K	P (mg kg^{-1})	OC (g kg^{-1})	pH (1:1 H_20)	Ca	Mg cmol kg^{-1}	K	P (mg kg^{-1})	OC (g kg^{-1})	pH (1:1 H_20)	Ca	Mg cmol kg^{-1}	K	P	OC (g kg^{-1})	pH (1:1 H_20)	Ca	Mg cmol kg^{-1}	K	P (mg kg^{-1})	OC (g kg^{-1})	pH (1:1 H_20)
M^+ CT	2.67	0.54	0.13	24.77	5.6	6.03	2.43	0.51	0.12	11.44	5.4	6.13	2.72	0.43	0.14	23.96	5.8	5.9	2.57	0.45	0.12	10.87	5.6	6.0
M^+ ZT	2.73	0.53	0.15	25.57	5.8	5.43	2.43	0.49	0.12	11.03	5.5	6.00	2.69	0.43	0.15		5.8	5.8	2.65	0.47	0.12	10.74	5.7	5.9
M^- CT	2.62	0.49	0.15	26.53	5.5	6.05	2.38	0.46	0.10	9.82	5.3	6.10	2.69	0.40	0.14		5.4	5.9	2.32	0.41	0.10	11.69	5.3	6.0
M^- ZT	2.63	0.48	0.17	27.81	5.4	5.93	2.39	0.47	0.10	10.29	5.3	6.00	2.89	0.43	0.16	27.70	5.5	5.8	2.45	0.46	0.11	10.57	5.5	5.9
LSD (0.05)																								
Fertilizer	0.15	NS	0.02	NS	NS	NS							0.21	NS	0.018	3.11	NS	NS						
Mulch	NS	NS	NS	NS	NS	NS							NS	NS	NS	NS	NS	NS						
Tillage	NS	NS	NS	NS	NS	NS							NS	NS	NS	NS	NS	NS						
M x F	NS	NS	NS	NS	NS	NS							NS	NS	NS	NS	NS	NS						
F x T	NS	NS	NS	NS	NS	NS							NS	NS	NS	NS	NS	NS						
M x F x T	NS	NS	NS	NS	NS	NS							NS	NS	NS	NS	NS	NS						

Table 5. Effect of tillage, mulch and fertilizer on top soil (0-15 cm) chemical properties

Treat-ment	1983												1984											
	Fert						No Fert						Fert						Fert					
	Ca	Mg cmol kg^{-1}	K	P (mg kg^{-1})	OC (g kg^{-1})	pH (1:1 H_2O)	Ca	Mg cmol kg^{-1}	K	P (mg kg^{-1})	OC (g kg^{-1})	pH (1:1 H_2O)	Ca	Mg cmol kg^{-1}	K	P	OC (g kg^{-1})	pH (1:1 H_2O)	Ca	Mg cmol kg^{-1}	K	P (mg kg^{-1})	OC (g kg^{-1})	pH (1:1 H_2O)
M^+ CT	1.93	0.40	0.09	9.24	0.34	5.65	1.88	0.39	0.08	4.36	0.30	5.60	2.04	0.38	0.07	9.75	0.33	5.6	2.21	0.43	0.08	4.93	0.34	5.8
M^+ ZT	2.00	0.37	0.09	5.24	0.30	6.63	2.07	0.35	0.08	3.58	0.27	5.60	2.12	0.37	0.07	5.80	0.25	5.5	2.19	0.40	0.07	4.60	0.29	5.6
M^- CT	2.10	0.37	0.10	9.19	0.28	5.55	1.99	0.36	0.08	4.05	0.32	5.70	2.37	0.41	0.08	7.94	0.32	5.5	2.23	0.40	0.07	4.63	0.29	5.6
M^- ZT	2.15	0.35	0.08	5.45	0.28	5.53	1.97	0.37	0.07	3.91	0.26	5.50	2.21	0.39	0.07	5.50	0.28	5.5	2.17	0.43	0.07	3.97	0.76	5.6
							2.39																5.5	
LSD (0.05)																								
Fertilizer	NS	NS	0.01	0.98	NS	NS							NS	NS	NS	0.86	NS	NS						
Mulch	NS	NS	NS	NS	NS	NS							NS	NS	NS	0.86	NS	NS						
Tillage	NS	NS	NS	0.98	NS	NS							NS	NS	NS	0.86	NS	NS						
M x F	NS	NS	NS	NS	NS	NS							NS	NS	NS	NS	NS	NS						
F x T	NS	NS	NS	NS	NS	NS							NS	NS	NS	NS	NS	NS						
M x F x T	NS	NS	NS	NS	NS	NS							NS	NS	NS	NS	NS	NS						

significantly affected by tillage and fertilizer treatments. The greater accumulation of plant nutrients-P, Ca, Mg and K in the top soil of zero tillage as compared with conventional tillage may probably be associated with surface application of fertilizers without mixing. Similar results have been reported (12 and 24). It is also likely that the higher organic C in the surface soil of zero tillage will have preferentially retained the exchangeable cations. Alternatively, the decrease in the amounts of these elements in conventional tillage plots may be due to dilution of the surface soil with subsoil and greater leaching and erosion losses. Ike (10) attributed lower exchangeable K values in conventional tillage to greater leaching and erosion losses. The significantly higher subsoil P may be due to the incorporation of the fertilizer at land preparation.

CONCLUSION

Under continuous use for crop production, these soils may need to be periodically tilled so as to reduce soil compaction which could easily develop if untilled for a long time. The use of crop residues as mulch can effectively reduce bulk density and penetrometer resistance of surface layers by preventing rain drop impact and surface crusting. Nutrient accumulation in the top soil is generally common with zero tillage than conventional tillage probably because of the surface application of fertilizers. Mulching, in addition to its effect on bulk density and penetrometer resistance tend to increase the organic C and nutrient contents of these soils. Fertilizer application reduces the pH of these soils. Nitrogen fertilizer may be particularly responsible for this effect. Zero tillage tends to reduce soil pH. The differences in Mg content of the soil before and after the two seasons emphasis the need for application of Mg fertilizer in these soils.

Although the differences obtained in this study are small probably due to the relatively short duration of the experiment, they are of interest principally as early indicators of the possible long-term trend in these soils especially if they are intensively cropped.

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TILLAGE REQUIREMENTS FOR SUSTAINING RICE-WHEAT PRODUCTION IN A SUB-TROPIC CALCAREOUS SANDY LOAM OF NORTH-BIHAR, INDIA

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ABSTRACT

Four tillage practices imposed in rice-wheat cropping seasons in that sequence as zerotill-zerotill(T_0), conventional-conventional (T_1), semideep-semideep (T_2) and conventional-zerotill (T_3) were evaluated in a field experiment over four consecutive seasons during 1987-89 on a sub-Tropic calcareous sandy loam soil at Pusa, India. Animal and tractor drawn mould-board ploughs respectively were used for effecting conventional and semideep tillages of 13 and 27 cm depths. Two levels of 50 and 100 kg N ha^{-1} rice and 60 and 120 kg N ha^{-1}in wheat were superimposed over tillage practices in three replications. Soil hydraulic conductivity in rice fields at crop harvest differed significantly ($p<0.05$) for tillage practices with zero and semideep tillage resulting respectively in the highest and lowest values and also exhibiting a similar effect on cumulative infiltration. Consequently, rate of water loss from rice fields at various stages also differed significantly ($p<0.05$) with two-year average values of 1.03, 0.71, 0.51 and 0.75 mm h^{-1} respectively for T_0, T_1, T_2 and T_3 treatments. Semideep tillage thus reduced the rice water requirements by about 32 cm (29%) with a significantly ($p<0.05$) higher two-year average grain yield of 3.61 Mg ha^{-1} and also resulted in the highest net energy and economic returns of respectively 123.3 x 10 MJ and US \$ 309.4 $ha.^{-1}$ In the succeeding wheat crop, zero- and semideep tillage had just the opposite effect with the former and latter respectively showing the lowest and highest values of hydraulic conductivity and cumulative infiltration. Wheat grain yield differed significantly for tillage practices but was at par for conventional (T1) and semideep (T_2) tillage with a two-year average yields of 2.57 and 2.59 Mg ha^{-1} respectively. The net energy and economic returns from wheat being respectively 98.9 x 10 MJ and US \$ 188.2 ha^{-1}were highest for the conventional tillage. Thus semideep for rice, followed by conventional tillage for succeeding wheat appears to be the most appropriate practice for rice-wheat sequence.

INTRODUCTION

Tillage is one of the energy intensive inputs of agriculture. In developing countries, the share of tillage in total input in agriculture has been estimated to be about 75 per cent indicating thereby that any improvement or increase in efficiency of tillage practices will have positive effects (1). Furthermore, while sub optimal tillage reduces crop yields, any excessive tillage, besides entailing high cost, degrades the soil and pollutes the environment. Therefore, location and cropping system specific tillage practices which create and maintain soil conditions favourable for enhanced and sustained productivity need to be identified for various areas. In the present investigation therefore, an attempt has been made to identify appropriate tillage practices for a widely adopted rice-wheat cropping system in the alluvial plains of north-Bihar, India.

MATERIALS AND METHODS

In order to evolve a suitable tillage system for sustaining rice-wheat production, four different tillage practices were evaluated in a field experiment over four consecutive cropping seasons during

1987-89 at the experimental farm of the Rajendra Agricultural University, Bihar, Pusa. India. The soil of the experimental field was calcareous sandy loam having 63, 25 and 11 per cent sand, silt and clay respectively with a pH of 8.3 and free $CaCO_3$ content of 29.3 per cent. Below 20 cm depth, the texture was silt loam.

The four tillage practices imposed in rice-wheat cropping seasons for two successive years were : zerotill (rice)-zerotill (wheat), conventional (rice)-conventional (wheat), semideep (rice)-semideep (wheat) and conventional (rice)-zerotill (wheat) designated respectively as T_0, T_1, T_2 and T_3. Dibbling method was used for transplanting of rice as well as sowing of wheat and no tillage other than manual weeding was done in zerotill plots. For conventional tillage, field was puddled/ploughed twice at 90 to each other for rice/wheat to a depth of 13 cm using animal drawn mould-board plough. The semideep tillage was effected by puddling/ploughing the field twice in a similar manner using tractor drawn mould-board plough to 27 cm depth. The tractor was mounted with cagewheel while carrying out puddling for rice. Two plankings after puddling/ploughing were common to both conventional and semideep tillage. Two levels of nitrogen viz., 50 and 100 kg ha for rice and 60 and 120 kg ha^{-1} for wheat were superimposed in 10 x 8 m subplots over the tillage practices in the main plots of 21 x 8 m size for both crops. Treatments were replicated three times in a split plot experiment leaving a headland of 1 m within and between the blocks. Half of the nitrogen was applied at the time of transplanting/sowing of rice/wheat and the remaining half in two equal splits at active tillering and penicle initiation stages in both the crops. Phosphorous @ 60 kg P_2O_5 and potassium @ 40 kg K_2O ha^{-1} were both applied in full dose at the time of transplanting of rice and sowing of wheat. Twenty centimeter high dykes were made around rice plots to avoid runoff. Rice cv. Saket-4 and wheat cv. HP 1102 were used as test crops.

Rate of water loss (ET + Percolation) from rice plots at different stages was measured at 12 h interval between 06:00 and 18:00 h using open end cylinder method at four sites in each plot. Measurements after harvest of both crops included saturated hydraulic conductivity of upper 10 cm soil, infiltration rate using double ring infiltrometers and grain yield of paddy and wheat. Energy inputs and outputs were computed using standard energy coefficients (5). Economic returns were also computed.

RESULTS AND DISCUSSION

Rice

Data in Table 1 on saturated hydraulic conductivity of soil (hereafter, HC) revealed that it was significantly ($p<0.05$) affected due to tillage practices in both years for both the crops. For rice fields, HC of 0.71 and 0.62 cm h^{-1} respectively in 1987 and 1988 was highest for zerotill (T0) and 0.33 and 0.23 cm h^{-1}respectively for the same years was lowest for semideep tilled (T_2) plots The HC values for conventionally tilled (T_1) plots were intermediate between these two extremes and were close to those of T_3 plots which were also tilled conventionally during rice cropping season. The trend observed for HC in respect of tillage practices appears all the ore logical when viewed along with the data on cumulative infiltration and infiltration rate (Fig. 1a) measured over a period of 360 minutes during 1987. It is obvious from the data that cumulative infiltration and infiltration rate were both highest for zero- and lowest for semideep tilled plots with conventionally tilled plots showing values that were intermediate in magnitude. Similar trend was observed (data not presented) in the subsequent rice cropping season of 1988 when measurements were made over a period of 420 minutes.

The differential effect of tillage practices on the HC and infiltration rate appears to be responsible for variable rate of water loss under different tillage practices (Table 2). During both years and on all observation dates, the rateof water loss was significantly ($p<0.05$) affected by the tillage practices with zero- and semideep tilled plots showing respectively the highest and lowest rates. For conventionally tilled (T_1 andT_3) plots the rate of water loss was higher than for semideep but lower than for zerotill plots

Table 1 Effect of tillage practices on saturated hydraulic conductivity of soil, cm h-1, in rice-wheat cropping sequence on a calcareous sandy loam soil

Tillage practice	Rice			Wheat		
	1987	1988	mean	1987-88	1988-89	mean
T_O	0.71	0.62	0.66	0.50	0.54	0.52
T_1	0.37	0.32	0.34	0.60	0.63	0.61
T_2	0.33	0.23	0.28	1.23	1.45	1.34
T_3	0.36	0.30	0.33	0.54	0.57	0.55
LSD (.95)	0.03	0.07		0.08	0.38	

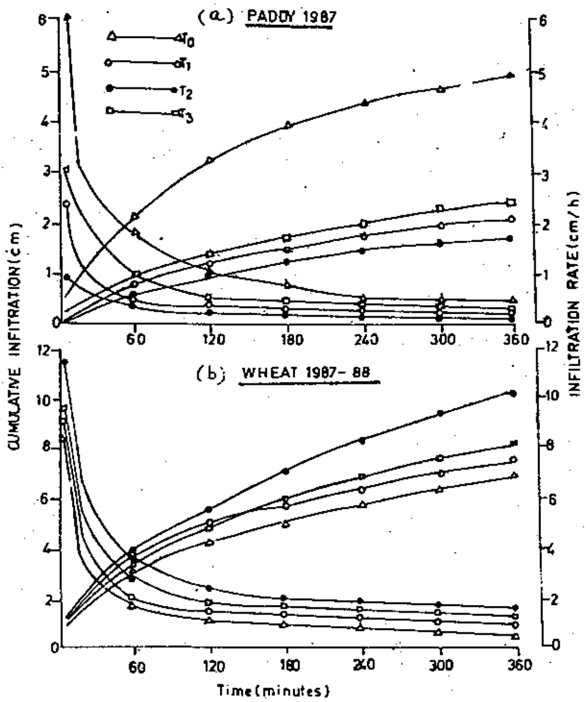

Fig. 1: EFFECT OF TILLAGE ON CUMULATIVE INFILTRATION AND INFILTRATION RATE AFTER HARVEST OF PADDY AND WHEAT

Table 2 Effect of tillage practices on rate of water loss, mm h^{-1}, from rice fields during 1987 and 1988 in calcareous sandy loam soil

Days after transplanting	Tillage practice				
	T_0	T_1	T_2	T_3	LSD(.05)
	1987				
26	1.43	0.82	0.45	0.84	0.15
29	0.95	0.70	0.53	0.68	0.09
31	1.03	0.68	0.43	0.70	0.24
33	0.80	0.60	0.43	0.56	0.10
36	0.84	0.54	0.40	0.61	0.18
37	0.80	0.61	0.43	0.63	0.05
38	0.85	0.69	0.48	0.68	0.14
40	0.89	0.61	0.43	0.63	0.05
52	0.90	0.66	0.46	0.72	0.08
56	0.85	0.63	0.32	0.78	0.09
70	1.39	0.87	0.52	0.78	0.37
75	1.48	0.96	0.88	1.13	0.20
Mean	1.01	0.69	0.48	0.72	
	1988				
28	1.62	0.93	0.52	0.93	0.18
34	1.02	0.73	0.50	0.78	0.22
37	0.95	0.74	0.73	0.83	0.11
40	0.81	0.67	0.56	0.72	0.14
42	0.73	0.65	0.58	0.65	0.07
46	0.76	0.56	0.46	0.65	0.05
48	1.48	0.92	0.51	0.93	0.37
Mean	1.05	0.74	0.55	0.78	
Overall mean	1.03	0.71	0.51	0.75	

Averaged over two years, the rate of water loss from rice fields was found to be 1.03, 0.72, 0.51 and 0.75 mm h^{-1} respectively for T_0, T_1, T_2 and T_3 plots. Nitrogen levels had no effect on these parameters.

Table 3 Effect of tillage practices on grain yield, Mg ha^{-1}, of paddy and wheat in rice-wheat cropping sequence in a calcareous sandy loam soil

Tillage practice	Paddy			Wheat		
	1987	1988	Mean	1987-88	1988-89	Mean
T_0	2.54	1.73	2.13	1.15	1.48	1.81
T_1	3.33	2.84	3.08	2.80	2.35	2.57
T_2	3.64	3.59	3.61	2.70	2.49	2.59
T_3	3.18	2.75	2.96	2.06	1.61	1.83
LSD(.05)	0.22	0.39		0.25	0.14	

Grain yield of paddy (Table 3) which was affected significantly ($p<0.05$) due to tillage practices in both the years was also highest with a two-year mean value of 3.61 Mg ha^{-1} for semideep (T_2) and lowest with a value of 2.13 Mg ha^{-1} for zerotill (T_0) plots. The yields of conventionally tilled

T_1 and T_3 plots were at par with each other. Consequently, the net energy returns of 123.3 x 10 MJ and net econonic returns of US \$ 309.4 ha^{-1} (Table 4) were also highest for semideep (T_2) and with respective values of 79.4 x 10 MJ and US \$ 81.9 ha^{-1} were lowest for zerotill (T_0) plots. Higher nitrogen level of 100 kg ha^{-1} showed significantly ($p<0.05$) higher paddy grain yield than the lower level (not presented).

Table 4 Effect of tillage practices on net energy (x 10^3 MJ ha^{-1}) and net economic (US \$ ha^{-1}) returns from rice-wheat cropping sequence on a calcareous sandy loam soil. Average of 2 years. Conversion rate 1 US \$ = 18 Indian Rupees.

Tillage practice	Net energy returns Rice	Wheat	Net economic returns Rice	Wheat
T_0	79.4	63.6	81.9	61.9
T_1	117.0	98.9	252.3	188.2
T_2	123.3	98.0	309.4	153.1
T_3	114.4	69.6	236.7	78.9

It is thus apparent from the above results that semideep tillage (T_2) not only resulted in the highest grain yield, net energy and net economic returns but also reduced rice water requirements by about 32 cm (29%) of the normal requirements of 110 cm established for conventionally tilled conditions for this soil (8).

Wheat

The HC of wheat fields was also affected significantly ($p<0.05$) due to tillage practices but with zero and semideep tillage affecting it in a manner just opposite to that observed for rice fields. The lowest and highest HC values of 0.52 and 1.34 cm h^{-1} were thus observed for zero and semideep tilled plots respectively. Furthermore, the HC values of T_3 plots during both the years were closer to those of zerotill rather than T_1 as was observed in case of rice. This was quite logical as T_3 plots were tilled conventionally during rice season but were changed to zerotill during succeeding wheat season. Effect of tillage practices on cumulative infiltration (Fig 1b) was similar to that observed for HC. Nitrogen levels had no effect either on HC or cumulative infiltration.

Tillage practices had a significant ($p<0.05$) effect with zero- and semideep tilled plots respectively showing the lowest and highest grain yields in both years. However, yields of semideep- and conventionally tilled plots with two-year average values of 2.59 and 2.57 Mg ha^{-1} respectively were at par with each other and that of T_3 plots was closer to T_0 plots. Consequently, the net energy and economic returns (Table 4) being respectively 98.9 x 10 MJ and US \$ 188.2 ha^{-1} were highest for conventionally tilled and with respective values of 63.6 x 10 MJ and US \$ 61.9 ha^{-1} were lowest for zerotill plots. The T_3 plots showed values closer to those of T_0 plots. The effect of nitrogen levels on grain yield (not presented) was also significant.

Probable reasons for results obtained are discussed as follows. The maximum values of HC and cumulative infiltration resulting in turn the highest rate of water loss from rice fields in zerotill plots could be ascribed to the continuity of capillaries (7) as the soil was not disturbed in these plots. On the other hand, broken capillaries to a grater depth and sealing of pores including that by free $CaCO_3$ to the maximum extent as a result of effective puddling in semideep tilled (T_2) plots appears to be responsible for their lowest values of HC, cumulative infiltration and in turn the rate of water loss (3). The intermediate values for these parameters in conventionally tilled plots indicates that the extent of puddling in these plots was lesser than that achieved in semideep tilled plots (9). The highest and lowest water loss respectively from zero- and semideep tilled plots could have caused the corresponding amount of nutrient loss especially the nitrogen along with percolating water resulting respectively in the lowest and highest yield of rice in these plots.

The reversal of trend of HC and cumulative infiltration in respect of zero- and semideep tillage in wheat fields could be attributed to increased surface (4) and thereby increased total porosity (2) in semideep tilled plots showing the highest HC as was observed by other workers (2). The lower wheat grain yield in case of T_0 and T_3 than T_1 and T_2 plots appears to have been caused due to unfavourable rhizosphere environment due to no tillage in T_0 and T_3 resulting in poor root growth and lower nutrient uptake. Conventional and semideep tilled plots, on the other hand, resulted in equally better rhizosphere environment for crop growth showing thereby similar yields in these plots.

CONCLUSION

Based upon results presented above, it is concluded that semideep tillage in rice followed by conventional tillage in succeeding wheat appears to be the appropriate tillage practice for sustaining higher rice-wheat production in sub-Tropic calcareous sandy loam soil of alluvial plains of north-Bihar, India.

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A NEW ROTATION TILLAGE SYSTEM FOR RICE-WHEAT MULTIPLE CROPPING IN JIANGSU, CHINA

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ABSTRACT

Three different tillage methods in five different farming regions of Jiangsu, China, were surveyed by location test to examine how these tillage methods affect the soil fertility and the yields of rice and wheat. The results showed that sowing at the same term, the yield of wheat with minimum or no-tillage was more probable to increase, with a greater increment on clayey loam than on sandy loam; the yield of hand transplanted rice in no-tillage treatment tended to decrease, with a greater decrement on clayey loam than on sandy loam also; and both the change ranges tended to increase gradually from raised south to north ($32^{0}10'N$--$43^{0}30'N$). Minimum or no-tillage had notably the nutrient enrichment in surface soil, but the soil bulk density below 7 cm decreased, and organic matter, available nitrogen, phosphorus, and potassium all tended to decrease. Comprehensive analysis of soil fertility indicated that as for fertility enhancement, minimum- or no-tillage was more advantageous for clayey loam than for sandy loam. Based on these results, a new rotation tillage system has been established, in which minimum tillage is the principal part combining with periodically rotation of deep, shallow and no-tillage. This new system integrated the merits of different tillage methods and correctly handled the time contradictions between multiple cropping and farming season, farming and promoting the soil fertility, high yield and high efficiency, therefore, had significant impact on state's agro-economics.

INTRODUCTION

Development and application of minimum or no-tillage technology is a growing interest in China since 1980's and its mechanisms and techniques has been developed and studied extensively(1,2). However, some technical problems involved in application of this new tillage is still unsolved, such as whether it is necessary to deep plowing after minimum or no-tillage or not? How long is the optimal time interval between deep plowing and minimum or no-tillage and how to rotate among the different tillage methods? Our objective of this research is to answer those questions and to established a new and efficient rotation tillage system for rice-wheat multiple cropping in southern China.

MATERIALS AND METHODS

This research was conducted in five different farming regions of Jiangsu province in southern China for four to ten years. Experimental soils covered a large variety of soil physical and chemical characteristics represented in Jiangsu province. Three main treatments used in this experiment were conventional tillage (plow depth 14 cm), minimum tillage (plow depth 5-7 cm) , and no tillage (plow depth 0-3 cm), with three replications. The randomized block experimental design was used in this research. In order to establish an efficient rotation tillage system covered different various cropping patterns, we conducted a series of subtreatment trials, including different tillage combination; tillage effects on yields under no fertilization; wet plow and seeding; mulching; dry effects of plowing; various combinations of fertilization methods and rates; soil compaction and plant growth; and radio isotope trace tests.

RESULTS AND DISCUSSION

Effects of different tillage methods on yields of rice and wheat

Different combinations of different tillage methods were tested in five farming regions. Due to the large scale of soil textures, experiments were carried out in two main soil groups: sandy loam and clayey loam. Experimental results showed that minimum and no-tillage resulted in higher probabilities of yield increase on wheat than rice under rice-wheat cropping system (Table 1). This indicated that minimum or no-tillage in rice paddy can enhance the growth and yield of wheat, while the yield increase on rice by minimum or no-tillage is not significant due to low level of machinery operation in China. Therefore, the rotation approach of minimum and no tillage should be chosen in Southern China.

However, the differences on yields induced by different tillage methods under our experimental conditions didn't reach to statistically significant levels. Minimum and no tillage didn't resulted in significant yield increase during normal meteorological year, but they increased the yields significantly during the drought and flooding year (table 2). This implied that minimum or no-tillage system reduced the adverse effects of drought and flooding on crop yields. Under successive long-term minimum or no-tillage, the potential of wheat yield increase tended to decline. The results from long-term experiments at our experiments showed that during first three-year of minimum or no-tillage, wheat yield increased by 9.5% per year; during the later 7-year of minimum or no-tillage, the yield increased only by 3.4% per year. Other long-term experiments had the same decline tendency. The effective duration of wheat yield increase resulted from minimum or no tillage was about 2-3 years.

Effects of different tillage on soil fertility

Soil bulk density, soil moisture, and plant root system: it is scientific interest to show whether soil compaction induced by minimum or no-tillage will affect the plant root growth. The results from our experiments showed that there were no significant differences on

Table 1. Effect of no and minimum tillage on yields of rice and wheat on soils with different textures

Soil type	Site	Relative yields(yield of conventional tillage as 100)					
		Wheat			Rice		
		No. of test	Minimum tillage	No tillage	No. of test	Minimum tillage	No tillage
Sandy loam		9	108.8	108.0	9	100.8	94.6
		9	101.8	104.3	9	104.6	96.7
		9	103.7	99.6	6	101.7	102.9
		9	105.3	106.3	6	104.6	103.4
	Average		104.9	104.6		102.9	99.4
Clayey loam		9	104.4	115.4	9	93.1	92.6
		9	104.8	99.7	9	107.4	97.7
		9	101.8	112.1	9	94.1	92.6
		9	100.3	116.2	9	94.0	91.3
		7	90.9	91.6	6	105.8	104.1
	Average		100.4	107.0		98.9	95.7

Table 2. Effects of different climatic conditions on the yield of wheat with no and minimum tillage

Locality	Year	Main climatic characteristics	Wheat yield (% of conventional tillage)	
			No tillage	minimum tillage
Pen county	1987-88	flooding	124.1	104.8
	1988-89	normal	109.2	103.9
	1989-90	drought	112.9	104.5
Huaein	1987-88	flooding	101.5	107.6
	1988-89	drought	121.0	119.4
	1989-90	normal	101.7	99.8

soil bulk density under three-year no-tillage, except for surface layer (0-7 cm) of clayey loam. However, soil bulk density increased and excess the optimal value(2,3) of plant growth in layer of 7-14 cm at both soils under minimum tillage. This implied that long-term same tillage operation would result adverse soil compaction and affect plant growth. With periodical rotation of different tillage methods the soil would create its ability to adjust its aeration and prevent logged-layer, therefore, enhance the root system activity.

Table 3. Effects of different tillage methods on the contents of O.M. and total N of the soil

Soil type	Tillage method	Depth(cm)	O.M.(ton/ha)	Total N (ton/ha)
Sandy loam	No-tillage	0-7	13.725	0.909
		7-14	10.890	0.762
		14-21	7.185	0.570
		0-21	31.800	2.241
	Minimum tillage	0-7	13.665	0.893
		7-14	11.625	0.762
		14-21	7.515	0.585
		0-21	32.805	2.240
	Conventional tillage	0-7	12.495	0.856
		7-14	11.715	0.796
		14-21	7.650	0.578
		0-21	31.860	2.230
Clayey loam	No-tillage	0-7	18.675	1.205
		7-14	16.395	1.048
		14-21	11.910	0.876
		0-21	47.040	3.129
	Minimum tillage	0-7	16.875	1.059
		7-14	16.560	1.032
		14-21	13.125	0.917
		0-21	46.560	3.008
	Conventional tillage	0-7	16.095	1.008
		7-14	16.575	1.054
		14-21	14.625	0.949
		0-21	47.295	3.011

Soil nutrients and their distribution: effects of three-year different tillage methods on the contents of soil organic matter and total nitrogen were presented in table 3. These data showed that more O.M. and total N accumulated on surface layer (0-7 cm) after three-year minimum or no-tillage than conventional tillage, while some decrease in 7-

21 cm layer occurred under minimum and no tillage. No significant effects of different tillage methods on available N and P were observed. With successive long-term minimum or no-tillage, available K decreased rapidly, especially in low-available K soils. Decline on available K and P induced from minimum and no tillage is the problem needed to be further studied under minimum and no-tillage system.

Soil microbiology: changes on soil physical and organic matter distribution induced by tillage methods would affect the distribution of soil microbes. Microbe distribution pattern is responsible to the soil nutrients and root system distribution, and has a similar pattern of enrichment in surface layer of 0-7 cm. Under no-tillage system, biomass of soil microbes in top 0-7 cm layer contributed 53-84% of total biomass in 0-28 cm depth; while under conventional tillage, only about 24-56%. Nitrogen fixers and fibers decomposition bacteria in plow-layer after wheat under no-tillage were 3.7 and 5.6 times as those under conventional tillage, respectively. Fermentation microbes was the dominant species under no-tillage. The respiration intensity and urease activity in 0-7 cm top layer were much higher under no-tillage than these under conventional one.

Rotation tillage system and application for different farming regions in southern China

Determination of rotation pattern and time: many factors affect the determination of pattern and time of rotation tillage. The most important factor is the threshold period of the yield decline caused by deterioration of soil fertility under long term no-tillage. Soil O.M. contents also have a significant impact on the pattern of rotation tillage. Under minimum and no-tillage system, soils with high O.M. contents exhibit larger capacity to reduce the adverse effects caused by soil compaction of middle and lower layer than soils with lower O.M. contents. After analyzing various characteristics of soil compaction, Pidgeon (4) suggested that no-tillage system is not suitable for soils with lower O.M.. Huang et al(2) also demonstrated that soil O.M. content and bulk density can be used as the critical indicators for determination of pattern of rotation tillage. Results from effects of tillage methods on the crop yields (data not shown) of soils with different fertility suggested that with 4-year non-fertilization, both yields of wheat and rice under minimum and no-tillage were less than these under conventional tillage; while with fertilization treatment both yields under minimum and no-tillage were all higher than these under conventional one. This indicated that frequently plowing is necessary to maintain the high yield and prevent the soil compaction on low-fertility soils. With fertilization or higher O.M. content soils, the interval time between rotation tillage can be longer. This demonstrated that minimum or no-tillage system must be incorporated with fertilization for higher crop yields.

A new rotation tillage system and its application: Results from our experiments and surveys in five framing regions showed that continuous long-term no-tillage system on various type of soils did create a decline period on both soil fertility and crop yields. Thus rotation of different tillage is necessary for maintaining higher soil fertility and crop yields, in which minimum tillage is the fundamental part, minimum and no tillage system(Fig. 1) integrated the merits of different tillage methods. Periodically plowing can reduce the soil compaction, enhance the soil fertility, prevent the parasite diseases and control weed growth. This new tillage system has been applied for 3 years in Jiangsu province of southern China, extended to a total area of 794,000 ha, resulted in a net income of $\$7x10^8$, and gained significant social, economic, and ecological benefits.

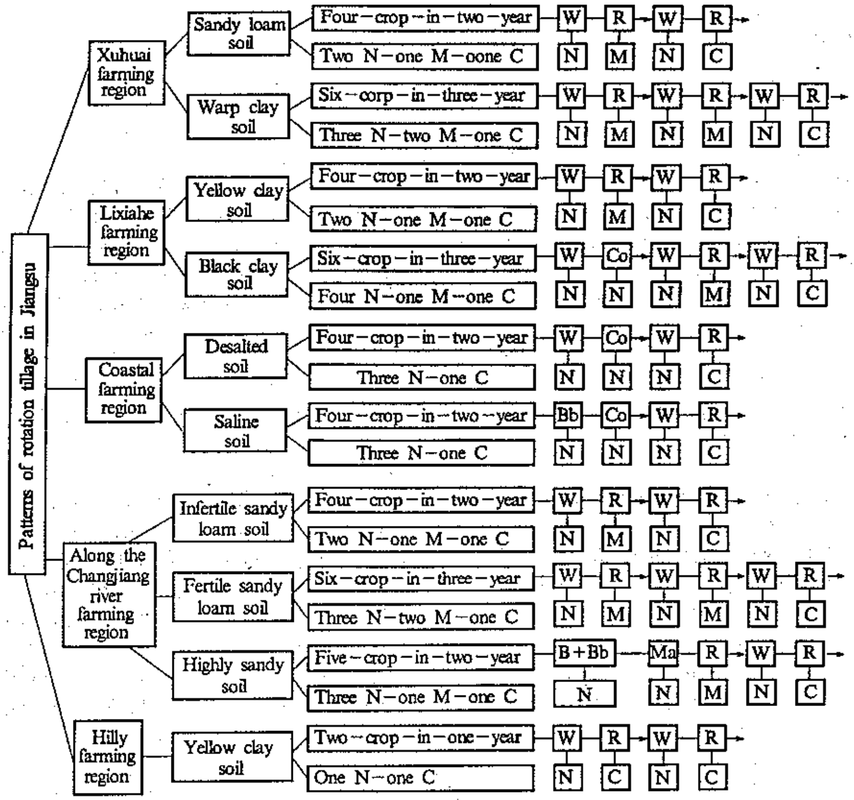

Fig.1 Rotation tillage patterns in different farming regions of Jiangsu province

Note: N-No tillage M-Minimum tillage C-Conventional tillage W-Wheat
R-Rice Co-Cotton Bb-Broad bean B -Barley Ma-Maize

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EFFECT OF TILLAGE SYSTEMS AND MULCH ON MAIZE AND COWPEA YIELD AND ON PHYSICAL PROPERTIES OF SANDY LOAM AND SILTY CLAY SOILS IN SOUTHEASTERN NIGERIA

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ABSTRACT

Changes in soil physical properties, water use, water use efficiency and yield response to tillage systems and mulch under rain-fed maize (April-July) - cowpea (September-December) rotation on sandy loam (Haplic Arenosols) and silty clay (Gleyic Cambisols) were evaluated in southeastern Nigeria. The study which commenced in 1992 involved four tillage practices, with or without mulch, namely: no-tillage with mulch (NT+M), no tillage without mulch (NT-M), conventional tillage (ploughing and harrowing) with mulch (CT+M), conventional tillage without mulch (CT-M), disc ploughing alone with mulch (DP+M), disc ploughing alone without mulch (DP-M), traditional farming "manual" system with mulch (TF+M) and traditional farming without mulch (TF-M). The experimental design was a randomized complete block with three replications.

Results obtained from four crops show that maize and cowpea growth and yield were better in the silty clay than the sandy loam soil. For both soil types, crop performance was better in the tillage and traditional farming plots than the no tillage plots. Mulcb application also significantly improved crop growth and yield. Water use for each soil type and each crop was similar under the different tillage practices but water use efficiency (WUE) for maize which was higher in sandy soil than silty clay soil was higher under tilled and traditional farming plots than untilled plots. Water use efficiency for cowpea was lower than that for maize in both soil types. Tillage and mulch effect on total porosity was significant only at some depths of both soil types.

Maize grain yield was significantly correlated with seedling establishment, plant height and WUE.

INTRODUCTION

Tillage systems and residue management practices have both direct and indirect effects on the soil envoirnment through their influence on soil properties and thus may effect the growth and yield of crops. The induced changes in the soil may be both beneficial and degradative, depending on the appropriateness or otherwise of the systems and practices used (Opara-Nadi, 1990; Ofori, 1991; Lal, 1993). Appropriate tillage systems which are climate-, soil-, and crop-specific are aimed at curtailing the degradation in soil properties and decline in crop yield (Lal, 1985). Orofi (1991) observed that although tillage effects on soils are closely related to the management of crop residues in and on the surface of the soil, the traditional ploughing in of crops residue is now gradually giving way to surface residue management, which is more related to soil and water conservation, particularly in the semi-arid tropics (SAT). Surface mulch, like appropriate tillage practice, helps to improve the soil environment for optimal crop growth and yield through its influence on soil physical, chemical and hiological properties (Lal, 1975; Unger, 1978; Opara-Nadi and Lal, 1987; Fernandez and Sanchez, 1990). Thus tillage and mulching play an important role in the dynamic processes governing agricultural sustainahility.

Rain-fed agriculture is prone to drought and therefore drought stress is an important factor limiting crop production even during the rainy season for soils in the humid and subhumid tropics (Hsiao et al., 1980; Osuji, 1984; Opara-Nadi et al., 1992). Consequently, efficient management of rain and effective utilization of soil water are vital for high and sustained yield of many rain-fed crops. Yield, being a function of many factors, is affected by soil and crop characteristics such as water use, water use efficiency and soil porosity, as well as the initial level of some other soil physical and chemical conditions. Water use and water use efficiency (WUE) are attributes of efficient management of rain and effective utilization of soil water. These attributes are, in turn, influenced hy tillage and soil surface management practices such as mulching. Despite the large volume of published data relating crop responses to different tillage systems and residue management practices, few studies (Kowal and Kassam, 1972; Osuji, 1984) examined the effects of tillage systems and mulching on water use and WUE in relation to crop yield. Since differences among crops and soil types is an important factor in crop and water management response to a given tillage system and crop residue management practice (Hatibu et al., 1991; Babalola and Opara-Nadi, 1990) there is need to study the effect of different tillage systems and residue management practices on soil water utilization and crop yield in different soils and ecoregions.

The objective of this study therefore was to evaluate the effect of different tillage systems with or without mulch on water use, WUE, porosity and on growth and yield of maize and cowpea grown in rotation for sandy loam and silty clay soils in southeastern Nigeria.

MATERIALS AND METHODS

Location and experimental layout

Field experiment were conducted at the Abia State University research farm (Site 1) and the International Secondary School teaching farm (Site 2), both at Uturu (5°50'N and 7°21'E) in southeastern Nigeria during the 1992 and 1993 cropping seasons. The study area lies at the northern limit of the high rainfall region of southeastern Nigeria. The climate is humid and supports derived savanna or forest savanna vegetation. The mean annual rainfall ranges between 1700 mm and 2000 mm and the rainfall pattern is bimodal (early April to the end of July and mid-August to the end of Octocber). The highest mean monthly temperature (30-40°C) occur between November and March. The soils used in the experiments are a sandy loam soil (Haplic Arenosols) and a silty clay soil (Gleyic Cambisol) according to FAO classification. Some chemical and properties of the 1-20 cm depth of the experimental soils at the two sites are shown in Table 1.

The experimental layout, which was the same at both sites, was a complete randomized block with three replications. Each replicate (40x32 m) consisted of eight plots to which eight treatments were randomly applied. The treatments were as follows: Treatment 1, traditional farming "manual" system, with mulch (TF+M); Treatment 2, traditional farming, without mulch (TC-M); Treatment 3, no tillage, with mulch (NT+M); Treatment 4, no tillage, without mulch (NT-M); Treatment 5, conventional tillage, with mulch (CT+M); Treatment 6, conventional tillage, without mulch (CT-M); Treatment 7, disc plouhing alone, with mulch (DP+M); Treatment 8, disc ploughing alone, without mulch (DP-M). Treatments 3 and 4 were the no-till treatments, with and without mulch respectively. Conventional ploughing involved discing and harrowing to about 20 cm depth with tractor-mounted implements. Treatments 7 and 8 involved discing alone. Prior to the present study, which started in February/March 1992, each site was under four-year fallow. The land was cleared manually. Mulching for the first crop (maize) of each year was at the rate of 6t ha^{-1} using fresh shoot (12 % moisture content) of guinea grass (Panicum maximum L.) applied immediately after planting, prior to herbicide application. Mulch application for the second crop (cowpea) was at the same rate using harvested shoot of maize from the first crop (8 % moisture content) and was applied also immediately after planting, prior to herbicide application. Weed control was done in the no tillage, conventional tillage and ploughing alone treatments by spraying with a mixture of paraquat (1-1', dimethyl-4-4' bipyridilium ion) at 2.51 ha^{-1} and atrazine (2-chloro-4-ethylamino-6-isopiopyl-amono-1, 3, 5-triazine) at 2.51 ba^{-1}. Weed control in the TF treatments was done bye hoe-weeding. Subsequent weed control in all treatments was done by hoe-weeding when necessary. All tillage operations were done in April 1992 and 1993 about two days before the first crop was sown. Fertilizer was applied in all plots at the rate of 120 kg ha^{-1} of 15:15:15 (N:P:K) at 4 WAP and a top dressing of the same fertilizer and rate at the tasseling stage for maize. Fertilizer application for cowpea was at the rate of 120 kg ha^{-1} of 15:15:15 (N:P:K) and at 4 WAP only.

Planting

Planting in all treatments was carried out on the flat. Maize (Zea mays L. variety TZSR-Y) was sown on 13 April and 13 May 1992 for the sandy loam soil (Site 1) and silty clay soil (Site 2), respectively with 90 cm between and 25 cm within rows. In 1993, maize was sown on 28 April and 18 May for the two sites respectively. Cowpea (Vigna unquiculata L. variety 82E-18) was sown on 25 and 28 August 1992 for sites 1 and 2 respectively and on 22 and 25 October 1993 for the two sites. Cowpea was sown at a spacing of 90 cm between rows (BR) and 20 cm within row (WR) and was sown at times besides the stumps of harvested maize without any seedbed preparation.

Observations

Maize plant height was measured from the ground surface to the growing tip and at 6, 8 and 12 WAP. Measurements were taken at random from 10 plants in each replicate. The maize was usually barvested in the 16th weed after planting. The cobs were shelled and the grain yields were determined at 12 % moisture content. Water use was determined from the weekly measurements of soil moisture profiles which were determined gravimetrically. Water use efficiency (WUE) was determined from data on water use, grain yield and dry matter production. Total porosity was determined from soil bulk density data measured on undisturbed cores (5 cm long and 5 cm internal diameter). One core sample was taken randomly between plant rows from each of five depths of 0-5, 5-10, 10-15, 15-20 and 20-40 cm and from each replicate of each treatment.

The matured and dried pods of the cowpea were harvested from the 10th week after planting as the pods matured. Data on water use, WUE and total porosity were determined for cowpea, using the same procedures described for maize.

RESULTS AND DISCUSSION

Plant height

Figure 1 shows the height of maize plants measured at 6, 8 and 12 WAP in 1993 at the two sites for the different tillage practices and mulch treatments. The trends for the measurements taken on the same WAP in 1992 were similar to the 1993 trends, and thus are not presented here. Plant height increased rapidly for all treatments up to the period of measurement (12 WAP). At this time, plant height was of the order: DP+M>DP-M>TF+M>CT+M>CT-M> NT+M>TF-M>NT-M. However, there was no significant difference in plant height between DP+M, DP-M, TF+M, CT+M and CT-M treatments at 12 WAP. Similar, there was no significant difference in plant height between CT+M, CT-M, NT+M, TF-M and NT-M treatments.

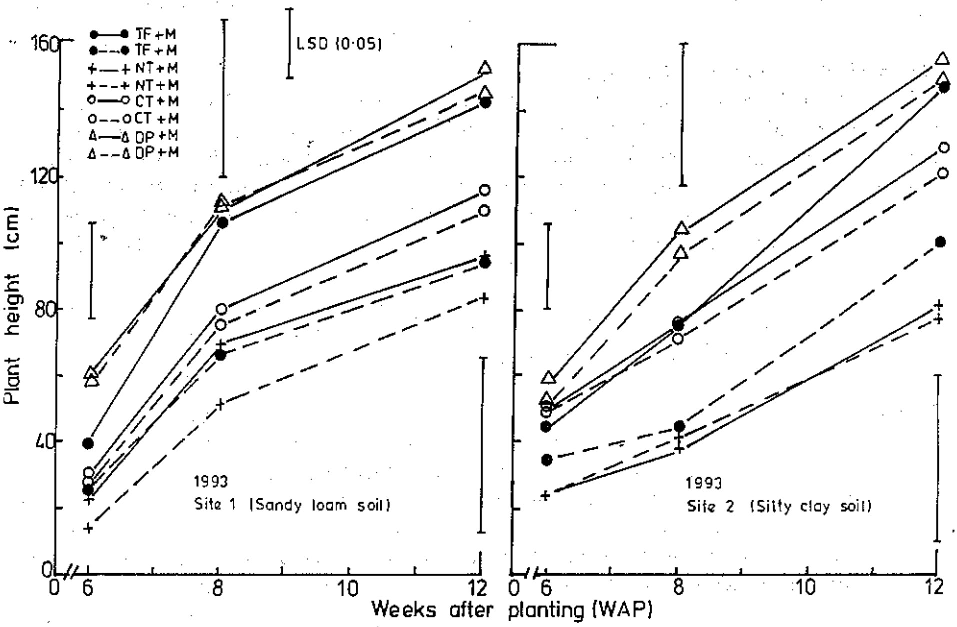

Fig. 1. Effect of tillage systems and mulching of height of maize in sandy loam and silty clay soil (1993 season).

Table 1. Some chemical and physical properties of the 0-20 cm depth of the experimental soils at the two sites.

Parameter	Property	
	Site 1	Site 2
pH (1:1 H_2O)	4.80	4.00
Organic carbon (%)	1.08	1.14
Total nitrogen (%)	0.04	0.04
Bray-II phosphorus	8.00	12.00
Exchangeable cations (meq 100 g^{-1})		
Calcium	0.31	2.00
Magnesium	0.11	1.20
Potassium	0.07	0.23
Sodium	0.02	0.03
Particle size distribution (%)		
Sand	84.90	62.90
Silt	0.30	14.30
Clay	14.80	22.80
Bulk density (g cm^{-3})	1.46	1.60
Total porosity (%)	44.90	39.60
Textural class	Sandy loam	Silty clay

Grain yields of maize and cowpea

The effects of tillage practices and mulching on the yield of maize in 1993 for both sites are presented in Table 2. The data show that grain yield in tilled and traditional farming treatments was significantly higher than in the no tillage treatments, with or without mulch. In 1992 and 1993, maize grain yield for the sandy loam soil was highest for the DP-M and TF+M respectively and lowest for the NT+M and NT-M for the same years respektively. However, there was no significant difference in yield between TF+M, CT+M, CT-M, DP+M and DP-M treatments. For the silty clay soil, maize yield in both 1992 and 1993 was highest for the DP-M treatment and lowest for the NT-M treatment. However, there was no significant difference in yield between DP-M and TF+M, CT+M, CT-M and PD+M treatments. The effect of mulching on maize yield was not significant.

Cowpea grain yield (Table 3) was significant affected by the tillage practices and mulching treatments. However, the effect of mulching alone on yield was not significant, even though the mulched treatments gave better yield than the unmulched treatments. Generally, grain yield was significantly higher in the tilled plots than in the no tillage plots. The higher yield in the tilled treatments can be attributed to better seedling establishment (not reported in this paper) in addition to improved conditions for crop production usually associated with tillage. Similar observations have been reported by Osuji (1984). The higher yield in the mulched treatments compared with the unmulched treatments may be due to better soil environment for crop growth arising from reduced erosion and other degradative factors (Osuji and Babalola 1982; Opara-Nadi and Lal, 1987).

Table 2. Effect of tillage methods and mulching on water use, maize yield and water use efficiency (WUE) on sandy loam and silty clay soils.

Year	Treatment	Water use (cm)	Grain yield (kg ha^{-1})	WUE (kg ha^{-1} cm^{-1})
Sandy loam soil				
1992	TF+M	25.4	2450	96.5
	TF-M	26.4	2050	77.7
	NT+M	19.7	1100	55.8
	NT-M	19.2	1300	67.7
	CT+M	27.4	2700	98.5
	CT-M	26.4	2850	108.0
	DP+M	25.9	3100	119.7
	DP-M	26.8	3250	121.3
	LSD (0.05)	10.5	910	42.1
1993	TF+M	29.2	2915	99.8
	TF-M	27.8	1075	38.7
	NT+M	22.4	550	24.6
	NT-M	19.9	200	10.1
	CT+M	31.6	2115	66.9
	CT-M	27.1	1835	67.9
	DP+M	32.3	2600	80.5
	DP-M	30.5	2700	88.5
	LSD (0.05)	13.8	1115	34.4
Silty clay loam				
1992	TF+M	42.5	2925	68.8
	TF-M	38.2	1925	50.4
	NT+M	28.7	1200	41.8
	NT-M	26.1	1075	41.2
	CT+M	39.3	2650	67.4
	CT-M	35.5	2475	69.7
	DP+M	44.8	3000	67.0
	DP-M	45.1	3440	76.3
	LSD (0.05)	20.1	1215	26.7
1993	TF+M	35.9	1725	48.1
	TF-M	31.3	1265	40.4
	NT+M	23.4	305	13.0
	NT-M	21.9	300	13.7
	CT+M	39.5	2710	68.6
	CT-M	36.2	2365	65.3
	DP+M	37.7	2690	71.4
	DP-M	39.4	2895	73.5
	LSD (0.05)	17.5	1445	36.8

Water use and water use efficiency

Data presented in Tables 2 and 3 show that for each soil type and crop, the total amount of water used within any one season did not vary much under different tillage and mulch treatments. The maize water-use values were slightly higher than those of cowpea. This is because low rainfall make the cowpea growing season a much drier season than the maize growing season. Generally, the maize water use falls within the range of 20-50 cm reported for maize by Osuji (1984).

Table 3. Effect of tillage methods and mulching on water use, cowpea yield and water use efficiency (WUE) on sandy loam and silty clay soils.

Year	Treatment	Water use (cm)	Grain yield (kg ha^{-1})	WUE (kg ba^{-1} cm^{-1})
		Sandy loam soil		
1992	TF+M	18.8	310	16.5
	TF-M	17.5	205	11.7
	NT+M	15.4	124	8.1
	NT-M	14.9	99	6.6
	CT+M	19.2	460	24.0
	CT-M	19.7	455	23.1
	DP+M	21.5	515	24.0
	DP-M	20.6	493	23.9
	LSD (0.05)	7.9	105	7.6
1993	TF+M	16.2	235	14.5
	TF-M	15.1	163	10.8
	NT+M	14.8	70	4.7
	NT-M	12.9	45	3.5
	CT+M	17.5	255	14.6
	CT-M	16.1	255	15.8
	DP+M	17.2	270	15.7
	DP-M	16.9	245	14.5
	LSD (0.05)	6.6	95	5.8
		Silty clay loam		
1992	TF+M	29.3	415	14.2
	TF-M	27.9	355	12.7
	NT+M	20.5	160	7.8
	NT-M	21.5	160	7.4
	CT+M	32.1	545	17.0
	CT-M	30.6	495	16.2
	DP+M	32.4	625	19.3
	DP-M	29.8	575	19.3
	LSD (0.05)	15.6	135	6.9
1993	TF+M	26.3	340	12.9
	TF-M	24.0	288	12.0
	NT+M	19.8	145	7.3
	NT-M	19.1	138	7.2
	CT+M	25.9	448	17.3
	CT-M	23.2	400	17.2
	DP+M	26.3	430	16.3
	DP-M	25.8	405	15.7
	LSD (0.05)	11.4	115	6.2

Water use efficiency (WUE) for grain production was significantly higher in the tilled and traditional farming plots than in the zero tillage for both maize and cowpea and for both soil types (Tables 2 and 3). The effect of mulching on WUE was not significant. Water use efficiency of maize was generally higher than that for coepea. Since WUE is largely dependent on yield and since grain yield of maize was higher than cowpea grain yield, this can explain the lower WUE of cowpea when compared the WUE of maize.

Maize grain yield (kg ha^{-1}) was significantly correlated with the following parameters:

Seedling establishment (%):	yield = -1693.98 + 59.26 (Est.)	$p = 0.01$, $r = 0.92$
Plant height (cm) at 12 WAP:	yield = -1256.88 + 28.30 (Ht.)	$p = 0.01$, $r = 0.80$
WUE (kg ha^{-1} cm^{-1}):	yield = 173.39 + 28.65 (WUE)	$p = 0.01$, $r = 0.87$.

Cowpea grain yield (kg ha^{-1}) was also significantly correlated with the following parameters:

Seedling establishment (%):	yield = -316.92 + 9.07 (Est.)	$p = 0.01$, $r = 0.76$
WUE (kg ha^{-1} cm^{-1}):	yield = 24.70 + 20.70 (WUE)	$p = 0.01$, $r = 0.80$.

Total porosity

Total porosity of the two soil types at different depths as affected by tillage methods and mulching is shown in Table 4. The effect of treatments on porosity was significant for only some depths of both soil types. Tillage effect on porosity was more pronounced than mulch effect.

Table 4. Total porosity of sandy loam and silty clay soils at different depths as affected by tillage methods and mulching (average for three early and two late seson crops).

Treatment	Total porosity (%)				
	Soil depth (cm)				
	0-5	5-10	10-15	15-20	20-40
Sandy loam soil					
TF+M	47,0	45,8	45,1	44,3	44,6
TF-M	45,5	43,8	43,9	43,5	44,8
NT+M	43,7	42,5	42,5	43,4	42,0
NT-M	44,2	43,4	43,5	43,7	43,3
CT+M	44,9	44,9	43,6	44,5	42,5
CT-M	44,7	43,5	43,2	43,7	43,0
DP+M	45,5	45,8	44,1	42,4	40,7
DP-M	45,0	46,7	44,6	44,3	43,4
LSD (0.05)	NS	3,5	NS	NS	4.1
Silty clay soil					
TF+M	40,9	39,1	39,1	37,2	36,2
TF-M	39,1	36,6	35,0	35,4	33,7
NT+M	39,2	37,4	38,3	36,3	36,4
NT-M	38,0	36,3	35,7	35,8	34,0
CT+M	40,6	40,4	38,3	38,1	37,2
CT-M	40,0	39,7	37,9	37,7	37,3
DP+M	40,7	40,2	38,5	37,1	35,8
DP-M	41,2	41,2	41,2	39,2	38,9
LSD (0.05)	NS	3,8	4,3	NS	4,0

CONCLUSION

(1) Disc ploughing alone (without harrowing) resulted in the best crop performance in terms of maize plant growth when compared with the other treatments.
(2) Tillage in combination with mulch improved maize and cowpea grain yields. However, the disc ploghing alone outyielded the conventional ploughing (ploughing and harrowing) treatments.
(3) The traditional farming "manural" treatment when combined with mulch resulted in increased plant height and maize and cowpea yields.
(4) Mulch effect on grain yield was more pronounced for cowpea than maize.
(5) Water use was not significantly affected by tillage practices and mulching treatments.
(6) Water use efficiency (WUE) was higher for maize than for cowpea and was equally higher in tilled and traditional farming treatments than in no tillage treatments.

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TILLAGE AND MULCH EFFECTS ON SOIL CRUSTING, SEEDLING EMERGENCE, ROOT GROWTH AND SOIL MOISTURE STORAGE IN THE DERIVED SAVANNA OF SOUTHEASTERN NIGERIA

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ABSTRACT

A 3-year field experiment was commenced in the 1992 planting season to evaluate the effects of no tillage (NT), conventional tillage, involving ploughing and harrowing (CT), disc ploughing alone (DP) and traditional farming "manual" tillage (TF) with mulch (+M) or without mulch (-M) on soil crusting, infiltration and soil moisture storage, seedling emergence and root growth of a maize (April to July) and cowpea (September-November) rotation. Two soils types, a coarse sandy loam and a silty clay were used in the experiment in a randomized complete block design with three replications.

Seedling emergence of maize and cowpea was better in the tilled and traditional farming treatments than in the no tillage treatment. Mulching had no significant effect on seedling emergence for all tillage systems. Plant population after emergence was closely related to the total area of soil surface of each treatment covered by crusts. Tillage and mulch gave significant increases in root weight and root length densities under tilled and traditional farming treatments when compared with the NT treatment, (+M) or (-M).

Cumulative infiltration after 2 h was highest in the DP+M treatment for the silty clay soil and CT-M treatment for the sandy loam soil and lowest in the NT-M treatment for both soils. Soil moisture content profile (0-40 cm) was significantly affected by tillage and mulch, with the tilled treatments having higher soil moisture content than other treatments. Soil bulk density and texture were also significantly affected by tillage systems and mulching. In all treatments, there was a general decrease in percentage clay content of the 0-5 cm depth with time and an increase in percentage sand and silt concentration.

INTRODUCTION

Tillage and mulching have long been recognized as important soil management practices which when judiciously used can serve as tools to alleviate some soil-related constraints to crop production such as soil surface crusting, compaction, low infiltration and unfavourable soil and temperature regimes (Lal, 1991; Aina et al., 1991; Benites and Ofori, 1993; Babalola and Opara-Nadi 1993). In addition, tillage and mulching positively or negatively affect some important crop and soil parameters such as seed germination, seedling emergence and stand establishment, root growth and crop yield, soil texture and bulk density, water retention and transmission characteristics.

Soil surface crusting is a common feature of many tropical soils, affecting both arid soils as well as cultivated soils of the humid environments (Adeove, 1985; Helalia et al., 1988; Valentin, 1991). When soil is cropped, servere crusting is observed, especially when land clearing and tillage operations are improperly performed (Kooistra et al., 1990; Benites and Ofori, 1993). Soil crusts may adversely affect seedling emergence and stand establishment, soil texture and bulk density, infiltration and moisture storage and, therefore runoff and erosion, hence losses of clay particles, organic matter and nutrients (Rathore et al., 1981; Jhoran & Agrawal, 1987; Helalia et al., 1988; Valentin et al., 1990; Valentin, 1991; Benites and Ofori, 1993). Consequently, the degree of crustation can be assessed by measuring seedling establishment and stand establishment, crust strength, infiltration and moisture storage, bulk density and rooting characteristics. Some studies (Kowal, 1972; Lal, 1975; Adeoye, 1985) have demonstrated that mulching can significantly reduce surface crustation, thereby enhancing seedling emergence and water infiltration. However, the influcence of tillage and mulching on soil properties and crop growth in relation to soil crusting for different soils has not been given the emphasis it deserves.

The objective of this study, therefore, was to evaluate the effect of tillage systems and mulching on seedling emergence, root growth, infiltration and moisture storage in relation to soil surface crusting for sandy and silty soils in the derived savanna zone of southeastern Nigeria.

MATERIALS AND METHODS

Location and experimental layout

The field experiment were conducted at two sites both at Uturu located at the northern limit of the high rainfall region of southeastern Nigeria. Details of the experimental locations, physical and chemical classification of the soils and experimental layout have been reported in an earlier paper (Opara-Nadi et al., 1994, in this proceedings) and therefore will be mentioned only briefly. The soil at site 1, a sandy loam is classified as Haplic Arenosols according to FAO classification system and Entisols according to Soil Taxonomy, while the soil at site 2, a silty clay is classified as Gleyic Cambisols (FAO) and Inceptisols (Soil Taxonomy) systems.

The effect of four tillage systems, with or without mulch were investigated for a maize - cowpea rotation in a randomized complete block design. Treatments were as follows: Treatment 1: traditional farming "manual" system, with mulch (TF+M); Treatment 2: tradtional farming, without mulch (TF-M); Treatment 3: no tillage, with mulch (NT+M); Treatment 4: no tillage, without mulch (NT-M); Treatment 5: conventional tillage (ploughing and harrowing), with mulch (CT+M); Treatment 6: conventional tillage, without mulch (CT-M); Treatment 7: disc ploughing alone, with mulch (DP+M); Treatment 8: disc ploughing alone, without mulch (DP-M). No tillage, conventional tillage and ploughing alone treatments were treated with a mixture of paraquat and atrazine to control weeds. Guina grass (Panicum maximum L.) shoot was used as mulch during the first season and maize stover from the first season crop was used as mulch during the second season. All tillage operations were done in April 1992 and 1993 for the first season crop of each planting year. Plot size was 5 by 4 m and maize was sown at a distance of 90 cm between and 25 cm within rows. Cowpea was sown at a spacing of 90 cm between and 20 cm within rows.

The degree of crustation as influenced by tillage systems and mulching on the plots was assessed by measuring a number of soil properties and plant growth parameters.

Measurement of soil properties

Soil bulk density and particle size distribution

Soil bulk density was measured 6 and 12 WAP for maize and 6 WAP for cowpea for both soil types. Soil samples were taken using undistured cores (5 cm long and 5 cm internal diameter). One core sample was taken randomly and approximately at the centre of the plant rows from eacb of five depths of 0-5, 5-10, 10-15, 15-20 and 20-40 cm and from each replicate of each treatment.

Particle size distribution of the 0-5 cm depth and the Ap horizon (1-12 cm depth) for the sandy loam soil depth) and Ap horizon (0-13 cm depth) for the silty clay soil was determined by the hydrometer method. For the 0-5 cm of both soil types a composite sample from all replicates of each treatment was used.

Water infiltration and soil moisture content

Infiltration was measured in 1992 and 1993 on both soil types with a double-ring infiltrometer at 6 and 12 WAP for maize and 6 WAP for cowpea. Measurements were approximately at the centre of the plot on two replicates of each treatment. All measurements were made over 2 h.

Soil moisture samples for gravimetric moisture content determinations were taken in 1992 and 1993 from both soils at 6 and 12 WAP for maize and 6 WAP for cowpea. Samples were taken from one location in each replicate and from 0-5, 5-10, 10-15, 15-20 and 20-40 cm depths. Gravimetric moisture content was converted into volumetric moisture content using the corresponding bulk density of each depth.

Measurement of crop growth parameters

Seedling emergence and root growth

Seedling emergence was recorded daily up to the 15th day after planting (DAP). The total number of emerged seedlings was used to calculate the percent seedling emergence.

Root growth was monitored at grain filling stage (12 WAP) for maize and 6 WAP for cowpea. Soil cores (8 cm in diameter and 10 cm deep) were taken at 0-10 and 10-20 cm between (BR) and within rows (WR) from all replicates of each treatment. The cores were taken broken horizontally and the roots exposed at the broken surface were sounted (Drew and Saker, 1977; Bohm, 1979). Root length density (RLD) in cm c^{-3}, soil and root weight density (RWD) in mg cm^{-3} were obtained from root number by the procedure of Drew and Saker (1977).

RESULTS AND DISCUSSION

Soil properties

Soil bulk density and particle size distribution

The effect of tillage systems and mulching on soil bulk density is shown in Table 1 for the sandy loam soil and Table 2 for the silty clay soil. For both soils, tillage has significant effect on bulk density of the 0-5, 5-10, 10-15, 15-20 and 20-40 in depths measured under maize and cowpea. For both soils, no difinite trend in hulk density in relation to tillage and mulching treatments has emerged. However, for the sandy loam soil, the DP+M, DP-M and TF+M treatments had lower bulk density than the other treatments. The NT+M and NT-M treatments has the highest bulk density for most of the depths measured. Mulching had no significant effect on bulk density for most depths under both crops. For the silty clay soil, although tillage had effects on bulk density, no definited trend had emerged. The effect of mulching on bulk density was not significant for most of the depths measured.

Table 1. Effect of tillage methods and mulching on soil bulk density (g cm^{-3}) sampled at 6 and 12 weeks after planting (WAP) on a sandy loam soil (1992 season).

	Bulk density (g cm^{-3})				
	Soil depth (cm)				
Treatment	0-5	5-10	10-15	15-20	20-40
Maize (6 WAP)					
TF+M	1.39	1.41	1.50	1.44	1.47
TF-M	1.45	1.57	1.51	1.52	1.50
NT+M	1.43	1.51	1.47	1.44	1.56
NT-M	1.43	1.48	1.52	1.49	1.48
CT+M	1.47	1.49	1.53	1.51	1.51
CT-M	1.43	1.48	1.50	1.48	1.47
DP+M	1.38	1.30	1.43	1.46	1.52
DP-M	1.35	1.34	1.50	1.52	1.46
LSD (0.05)	0.05	0.06	0.06	0.07	0.05
Maize (12 WAP)					
TF+M	1.41	1.42	1.45	1.46	1.44
TF-M	1.45	1.49	1.50	1.51	1.49
NT+M	1.48	1.50	1.52	1.54	1.55
NT-M	1.49	1.53	1.51	1.54	1.51
CT+M	1.45	1.44	1.49	1.50	1.49
CT-M	1.47	1.48	1.52	1.53	1.55
DP+M	1.39	1.42	1.45	1.48	1.51
DP-M	1.41	1.43	1.44	1.49	1.53
LSD (0.05)	0.06	0.08	0.05	0.06	0.09
Cowpea (6 WAP)					
TF+M	1.38	1.48	1.45	1.54	1.55
TF-M	1.43	1.44	1.48	1.48	1.44
NT+M	1.54	1.61	1.63	1.57	1.56
NT-M	1.52	1.50	1.48	1.47	1.55
CT+M	1.49	1.45	1.45	1.40	1.55
CT-M	1.53	1.60	1.53	1.40	1.50
DP+M	1.53	1.57	1.62	1.69	1.75
DP-M	1.58	1.43	1.48	1.45	1.52
LSD (0.05)	0.16	0.14	0.13	0.14	0.11

Table 2. Effect of tillage methods and mulching on soil bulk density (g cm^{-3}) sampled 6 and 12 weeks after planting (WAP) on silty clay soil (1992 season).

Treatment	Bulk density (g cm^{-3}) Soil depth (cm) 0-5	5-10	10-15	15-20	20-40
Maize (6 WAP)					
TF+M	1.66	1.59	1.58	1.61	1.64
TF-M	1.69	1.53	1.53	1.54	1.59
NT+M	1.63	1.53	1.49	1.59	1.59
NT-M	1.66	1.51	1.54	1.58	1.56
CT+M	1.57	1.53	1.63	1.59	1.68
CT-M	1.55	1.58	1.65	1.65	1.65
DP+M	1.58	1.53	1.55	1.60	1.64
DP-M	1.56	1.45	1.47	1.56	1.59
LSD (0.05)	0.07	0.08	0.11	0.08	0.10
Maize (12 WAP)					
TF+M	1.55	1.55	1.53	1.62	1.65
TF-M	1.62	1.75	1.76	1.80	1.81
NT+M	1.68	1.69	1.60	1.64	1.81
NT-M	1.63	1.67	1.83	1.73	1.79
CT+M	1.60	1.53	1.61	1.64	1.68
CT-M	1.60	1.55	1.59	1.66	1.69
DP+M	1.65	1.71	1.73	1.81	1.82
DP-M	1.58	1.56	1.56	1.60	1.62
LSD (0.05)	0.16	0.20	0.19	0.10	0.07
Cowpea (6 WAP)					
TF+M	1.53	1.56	1.55	1.61	1.64
TF-M	1.61	1.73	1.71	1.75	1.79
NT+M	1.67	1.68	1.62	1.66	1.78
NT-M	1.68	1.70	1.76	1.69	1.76
CT+M	1.61	1.59	1.61	1.69	1.65
CT-M	1.63	1.63	1.64	1.68	1.72
DP+M	1.59	1.70	1.71	1.72	1.80
DP-M	1.58	1.63	1.59	1.64	1.72
LSD (0.05)	0.07	0.11	0.11	0.12	0.13

Tillage and mulch had significant effect on particle size distribution for the two soil types (Table 3). For all treatments, there was a general decrease in percentage clay and an increase in percentrage sand and silt concentration. Losses of clay particles through run-off water and downward migration of clay particles by eluviation induced by tillage operations and seedbed preparation may have resulted in the changes in soil texture under all the treatments. This observation has been reported by Babalola and Opara-Nadi (1993). For the sandy soil, the TF+M, CT+M and DP+M treatments resulted in the least textural changes when compared with the other treatments. For the silty clay soil, the DP+M treatment resulted in the least textural changes. The mulched treatments resulted in lower losses of clay particles than the unmulched treatments for both soil types. Aina (1982) observed tbat mulching decreased the effect of tillage on changes in clay and silt content.

Table 3. Particle size distribution of the 0-5 cm depth of sandy loam and silty clay soils determined 6 WAP as influenced by tillage systems and mulching (1992 first season).

	Particle size distribution (%)					
	Sand	Silt	Clay	Sand	Silt	Clay
Treatment	Sandy loam soil			Silty clay soil		
TF+M	86.4	5.3	8.3	75.1	18.0	6.9
TF-M	90.4	3.0	4.6	77.1	18.0	4.9
NT+M	89.8	5.3	4.9	76.8	18.6	4.6
NT-M	90.4	6.3	3.3	77.1	20.0	2.9
CT+M	85.1	6.0	8.9	73.1	19.3	7.6
CT-M	91.1	3.3	5.6	75.1	18.0	6.9
DP+M	86.4	5.3	8.3	70.1	20.0	9.9
DP-M	90.4	3.0	4.6	75.1	20.0	4.9
Ap horizon (0-12 cm)	Ap horizon (0-12 cm)					
	86.9	2.3	10.8	64.9	16.3	18.8

Water infiltration and soil moisture content

Cumulative infiltration for different tillage and mulch treatments measured 6 WAP maize in 1992 for the sandy loam and silty clay soils is shown in Fig. 1 and Fig. 2 respectively. For the sandy loam soil, cumulative infiltration in the middle of two adjacent rows was highest for the CT-M and lowest for the NT-M treatment. For the silty clay soil, cumulative infiltration was highest for the DP+M treatment and lowest for the NT-M treatment. The effect of mulch on cumulative infiltration was more pronounced in the silty clay soil than the sandy loam soil. In general, infiltration was higher in the sandy loam soil than the silty clay soil.

Soil moisture profiles measured under cowpea in 1993 for the sandy loam and silty clay soils were significantly different among the different tillage and mulch treatments (Fig. 3).. Generally, volumetric moisture content of silty clay soil was higher than that of the sandy loam soil. For the sandy soil, volumetric moisture content was highest for the DP+M, CT+M and CT-M treatments and lowest for the TF-M, NT+M and NT-M treatments, while for the silty clay soil, volumetric moisture content was highest for the DP+M and CT+M treatments and lowest for the NT-M treatment. The tilled plots had better soil moisture reserve than the traditional farmning and no tillage plots. The effect of mulch on soil moisture content profiles was not significant. The higher moisture content in the tilled treatments may be due to higher porosity arising from the loosening of the soil when compared with the no tillage treatments.

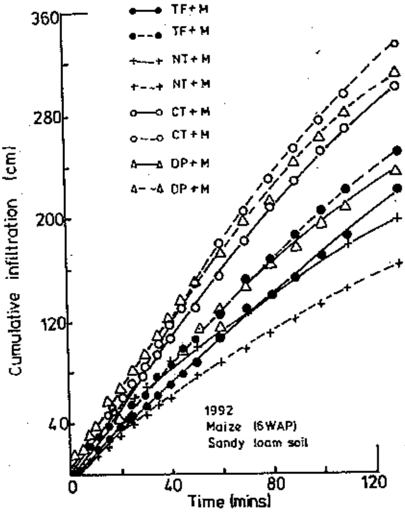

Fig. 1. Cumulative water infiltration under maize at 6 WAP for different tillage systems and mulching in a sandy loam soil.

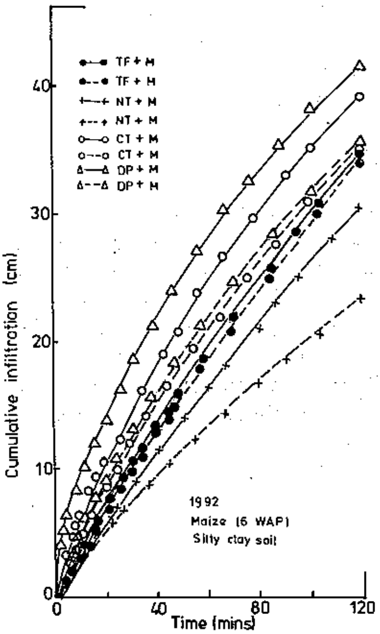

Fig. 2. Cumulative water infiltration under maize at 6 WAP for different tillage systems and mulching in a silty clay soil.

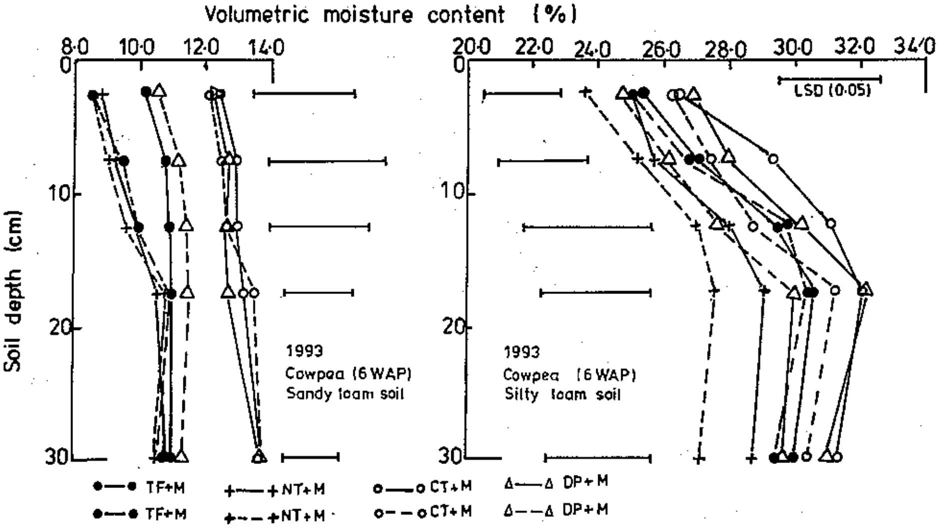

Fig. 3. Soil moistrue profiles under cowpea at 6 WAP for different tillage systems and mulching in sandy loam and silty clay soils.

Plant growth parameters

Seedling emergence

The effect of the different tillage and mulching treatments on seedling emergence of maize and cowpea for the sandy loam and silty clay soils in 1992 and 1993 is shown in Table 4. The treatment effect varied greatly with year, crop and soil. In general, seedling emergence of maize and cowpea was better in 1992 than 1993 for both soil types. For the sandy loam soil, maize seedling emergence in 1992 and 1993 was highest for the DP-M and TF+M treatments respectively and lowest for the NT+M in both years. For the same soil, cowpea seedling emergence in 1992 and 1993 was higbest for the DP+M treatment and lowest for the NT-M treatment. For the silty clay soil, seedling emergence of maize and cowpea in 1992 and 1993 and for both soil types highest for the DP+M treatment and lowest for the NT-M treatment. Generally, the tilled and traditional farming treatments gave better seedling emergence than the no tillage treatments. The effect of mulch on seedling emergence of maize and cowpea was not significant for most of the tillage systems. However, the mulched treatments gave better seedling emergence than the unmulched treatments.

Table 4. Effects of tillage methods and mulching on percent seedling establishment of maize and cowpea.

Treatment	Seedling establishment (%)							
	Sandy loam soil				Silty clay soil			
	Maize		Cowpea		Maize		Cowpea	
	1992	1993	1992	1993	1992	1993	1992	1993
TF+M	74.1	79.2	82.5	68.6	72.0	65.2	87.1	61.4
TF-M	61.7	58.4	80.8	65.8	54.1	59.3	84.5	59.3
NT+M	50.8	38.1	64.1	39.4	43.3	33.9	68.3	55.8
NT-M	57.6	37.4	58.2	36.7	37.6	45.6	56.2	54.9
CT+M	82.6	63.3	85.9	63.7	65.7	68.7	81.7	66.3
CT-M	84.6	57.4	87.3	60.5	69.7	62.8	78.3	61.7
DP+M	81.5	69.1	87.5	74.5	76.8	70.1	84.2	72.8
DP-M	86.7	72.1	81.7	74.1	73.5	71.1	79.5	70.9
LSD (0.05)	14.9	22.3	18.9	24.2	23.1	16.5	14.2	14.7

Root growth

Maize root length density for 0-10 and 10-20 cm depths measured between the plant rows (BR) and within rows (WR) at 12 WAP for the sandy loam and silty clay soils is shown in Table 5. Root length density was significantly different among tillage and mulching treatments. For the sandy loam soil, the BR and WR root density was highest under DP+M treatment and lowest under NT+M treatment. On the other hand, the BR and WR root length density varied among the different treatments for the silty clay soil. For example, the BR root density in the 0-10 cm depth was highest for the DP+M treatment and lowest for the NT-M treatment while the WR root density in this depth was highest for the CT+M treatment and lowest for the NT+M treatment. On the contrary, the BR root length density in the 10-20 cm depth was highest for the TF-M treatment and lowest for the CT-M treatment, while the WR root density for the same depth was highest for the DP-M treatment and lowest for the TF-M treatment. The effect of mulch on root length density was not significant for most of the tillage systems.

The effect of tillage systems and mulching on root weight density of maize for 0-10 and 10-20 cm measured between and within plant rows at 12 WAP for the sandy loam and silty clay soils is shown in Table 6. Although there were significant differences in root weight density among the different treatments, there was no definte trend. The effect of mulch on root weight density was significant for only some treatments and soil depths.

Table 5. Effect of tillage methods and mulching on maize root length density on two soil types sampled at the flowering stage (12 WAP).

Treatment	Seedling establishment (%)							
	Sandy loam soil				Silty clay soil			
	Between rows		Within rows		Between rows		Within rows	
	0-10 cm	10-20 cm	0-10 cm	10-20 cm	0-10 cm	10-20 cm	0-10 cm	10-20 cm
TF+M	0.59	0.33	0.59	0.43	0.21	0.26	0.21	0.13
TF-M	0.54	0.27	0.58	0.31	0.19	0.27	0.23	0.12
NT+M	0.10	0.13	0.30	0.35	0.21	0.13	0.17	0.16
NT-M	0.26	0.33	0.36	0.43	0.17	0.11	0.18	0.15
CT+M	0.60	0.34	0.67	0.53	0.27	0.11	0.40	0.14
CT-M	0.61	0.24	0.66	0.60	0.25	0.07	0.39	0.19
DP+M	0.65	0.63	0.73	0.74	0.39	0.18	0.31	0.21
DP-M	0.64	0.68	0.64	0.64	0.21	0.10	0.31	0.27
LSD (0.05)	0.31	0.24	0.21	0.27	0.08	0.09	0.11	0.09

Table 6. Effect of tillage methods and mulching on maize root weight density on two soil types sampled at the following stage (12 WAP).

Treatment	Root weight density (mg cm^{-3})							
	Sandy loam soil				Silty clay soil			
	Between rows		Within rows		Between rows		Within rows	
	0-10 cm	10-20 cm	0-10 cm	10-20 cm	0-10 cm	10-20 cm	0-10 cm	10-20 cm
TF+M	10.21	2.33	9.26	6.35	8.41	4.57	5.64	0.41
TF-M	6.82	0.48	9.35	1.84	7.27	0.78	5.84	0.64
NT+M	9.85	2.66	5.96	4.08	7.45	0.95	7.55	0.51
NT-M	2.40	1.76	3.00	2.32	4.85	0.37	3.99	0.73
CT+M	8.78	2.08	6.61	5.01	10.11	0.71	13.62	0.48
CT-M	4.82	1.18	2.16	1.78	10.90	0.64	9.31	1.02
DP+M	7.27	2.62	4.27	4.83	8.92	3.70	13.25	1.14
DP-M	7.02	2.16	4.27	2.90	7.57	0.67	10.60	0.80
LSD (0.05)	4.52	2.04	2.88	2.90	4.71	1.44	5.51	NS

Soil crusting

The degree of crustation as influened by tillage systems and mulching for the sandy loam and silty clay soils was assessed by measuring crop growth parameters such as seedling emergence and root growth and soil properties such as infiltration rate, particle size distribution of the soil surface, bulk density of the soil depth immediately below the surface and the moisture content of the crust (0-5 cm depth).

Seedling emergence of maize and cowpea was highest for the DP+M and DP-M treatments. The high emergence for the disc ploughing alone treatment is attributed to reduced soil crustation and less drying of the top soil following cyclic processes of wetting and drying during the cropping season. Adeoye (1985) and Benites and Ofori (1993 observed that crusting can be a problem when the soil dries out rapidly after a shower, and crusting just after seeding results in improper or poor emergence of the germinated seedlings. The poorer seedling emergence on the NT treatment might have been due to surface crusts which developed at or near tbe soil surface, in addition to clay dispersion and clogging of pores within the soil column. Crusts formed during the onset of the rains immediately after planting seal up the soil and consequently reduced infiltration rate of the soils under the different treatments. However, it was observed that crusts on tbe sandy loam was less stable than those on the silty clay soil. In addition, tillage and mulch reduced the impact of surface crustation, tbus the tilled and mulcbed treatments of the silty clay soil had higher infiltration rate than the no tilled treatments. Closely related to the formation of crusts on the surface is the clogging of pores when clay particles are dispersed. This clogging of pores reduces the moisture storage capacity of the soil. Thus, for example, the DP+M and CT+M treatments of the silty clay soil had about 3.3 and 2.8 percent higher moisture content at the 0-5 cm depth than the NT-M treatment. Losses of soil particles, especially clay particles through run-off water was induced hy tillage, surface custation and rainfall impact. The textural changes in all plots was, however, reduced by mulching. Aina (1982) observed that mulching decreased the effect of tillage on changes in the clay and silt content.

CONCLUSION

1. Crop growth and soil physical properties were more favouable in the tilled and traditional farming "manual" treatments than in the no tillage treatments.

2. Disc ploughing alone (without barrowing) resulted in the hest crop growth in terms of seedling emergence and root growth.

3. Water infiltration and soil moisture content were higher in the tilled treatments, with or without mulch than in the traditional farming and no tilled treatments.

4. Soil texture changes were induced by tillage and mulching treatments. There was a general decrease in percentage clay content with time and an increase in percentage sand and silt concentration.

5. Soil bulk density was significantly affected by tillage and mulching treatments but there was no definite trend among the treatments.

6. The effect of mulching alone on soil properties and crop growth was less pronounced that the effect of tillage. A higher rate of mulch greater than 6 t h^{-1} may be recommended for more pronounced changes in soil properties and crop growth.

7. The effect of soil surface crusting on soil properties and crop growth demonstrates than crusting is detrimental to crop growth and the overall sustainability of the system.

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TILLAGE SYSTEMS EFFECTS ON THE PERFORMANCE OF COWPEA IN NIGERIA

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ABSTRACT

Effects of tillage systems on the performance of cowpea (Vigna unguiculata, L.) was investigated on a sandy loam soil whose pedon belong to the order of Alfisol. Experimental treatments comprised conventional tillage using a disk plough followed by an offset disk harrow, shallow strip tilling with a rotary tiller, deep strip tilling with a chisel plough, paraploughing with a 3-bottom half-sweep plough and a no tillage, respectively. Soil strength variations with depth were determined. Also measured were depth of seed placement, tap root exploration, plant stand count and grain yield.

Results showed that soil dry bulk density and soil bearing capacity increased with increase in soil depth. This increase was least for conventional tillage. Result of the dry bulk density on no tillage plot showed similar increase with depth. Conventional tillage and paraploughing gave the greatest depth of seed placement while this observation was least for shallow strip tillage. Conventional and shallow strip tillage gave lower plant stand count than for other tillage treatments but such treatments did not offer significant effects for plant height, tap root exploration and grain yield measurements.

INTRODUCTION

Production of cowpea (Vigna unguiculata, L.) in Nigeria has been on the increase due, primarily, to the versatility of the crop. Market survey has shown a steady increase in price and production levels (Oyenuga, 1985). Production of cowpea however lacks a definite practice. While flat cultivation is being practised in some ecological zones, particularly in the southern states, traditional method of production on prepared ridges using handhoes predominates in some other production areas. Mechanical cultivation is however gradually being introduced.

Soil and crop performance in relation to tillage has been studied by several authors (Agrawal, 1978; Agrawal et al., 1984; Lal, 1979; Maurya and Lal, 1979; Nangju, 1979; Rodriquez and Lal, 1979; Oni and Adeoti, 1985) with somewhat varying results. The present study is to investigate the influence of different tillage systems on depth of seed placement, extent of tap root exploration, plant height plant stand count and grain yield.

MATERIALS AND METHODS

The experiment was conducted on a derived savannah soil showing sandy soil characteristics at A_1 horizon (0 - 10cm) and varying gradually to a loamy sand at A_{21} horizon (10 - 36 cm). The topography at experimental site is of a gradual slope varying between 5 and 10 per cent.

Experimental work commenced immediately after the land was cleared with no known record of recent cultivation at the site. Experimental layout consisted of a completely randomized statistical design comprising 9 blocks and 5 plots per block, giving a total of 45 treatment combinations. Each plot size was 3m x 10m. The tillage systems under investigation were:

i) conventional tillage consisting of disk ploughing to a depth of 20 cm with a 3-bottom disk plough followed by disk harrowing with a 2 m wide offset disk harrow;

ii) a shallow strip tillage with a rotary tiller driven by a tractor p.t.o at 540 rpm and operating to a depth of 10 - 15 cm;

iii) a deep strip tillage using a 3 m wide chisel plough with chisel points spaced 75 cm apart and operating to a depth of 25 cm;

iv) paraploughing with a 3-bottom, half-sweep paraplough to a depth of 25 cm; and

v) a no tillage

Tillage treatments were followed by planting cowpea with a rolling injection planter at a crop spacing of 25 cm on the row and a between row spacing of 75 cm. There were 4 rows of plants per plot. Crop planting was followed by an application of a pre-emergence herbicide consisting of a mixture of Gramozone, Galex and Round-up at a rate of 0.35 + 35 + 0.25 litre per hectare. Depth of seed placement was determined within 48 hours after sowing. Sampling was done at random over the experimental plots. The crop was thinned to two plants per stand followed by an application of superphosphate at a rate of 200 kg/ha.

The soil bearing capacity measurements were taken at 1, 5 and 10 weeks after sowing. This was achieved by using a 30 degree tip, 1.60 cm^2 base area handheld cone penetrometer equipped with a dial gauge pressure indicator mounted on its stem (Anonymous, 1985).

Soil dry bulk density measurement was carried out once on the no tillage plot at 5 weeks after sowing. This observation was indicative of the natural state of the soil prior to tillage treatments. Plant stand count was taken over the entire experimental plots at 2 weeks after sowing. At 57 days after sowing, the depth of tap root exploration and plant height measurements were taken. Cowpea pods were harvested at the end of the growing season and the threshed weight taken.

RESULTS AND DISCUSSION

Effect of soil bearing capacity

The soil bearing capacity showed an increasing trend with soil depth when measured along plant rows and between-the-rows, but no tillage consistently gave higher values for each depth investigated. This is illustrated by Table 1. For on-the-rows observations, paraploughing gave the least value of soil bearing capacity. While no tillage gave the highest value at each soil depth, conventional tillage was close in value to paraploughing while shallow strip tillage tended more towards no tillage. Table 1 further shows that the mean values for soil bearing capacity were significant for LSD and F-values at $P \leq 0.05$ for measurements made at 1,5 and 10 weeks after sowing. These data represent average values over all depths (0 - 30 cm) for each tillage treatment. This is further illustrated by Figure1.

Observations between-the-rows showed that soil bearing capacity values for conventional tillage was least while shallow strip tillage and deep strip tillage were higher than for the other tillage treatments. This trend was particularly distinct at 10 cm soil depth for between-the-row observations.

Table 1: Average values for the soil bearing capacity[i]

	Contact Pressure[j] (MPa)					
	Between rows			Within rows		
Treatment	1 w.a.s[k]	5 w.a.s	10 w.a.s	1 w.a.s	5 w.a.s	10 w.a.s
Conventional	324	603	2276	642	843	1970
Strip till (Shallow)	715	1110	2568	642	843	2191
Strip till (Deep)	649	948	2553	590	617	2043
Paraplough	317	577	2401	304	469	1742
No. Till	700	958	2498	651	914	2360
Standard Error (SE)	28.99	66.73	51.41	26.31	66.96	77.85
Coefficient of Variation (CV)	27.8	40.1	10.9	26.7	51.3	19.6
LSD.05	56.82	130.79	100.76	51.57	131.24	152.59
Degree of Freedom (DF)	122	199	122	122	122	122
F-values	48.99*	13.37*	5.59*	37.13*	8.23*	8.95*

[i] Averaged for all depths (0 - 30 cm) for each tillage treatment

j All observations taken in same year

k w.a.s. = weeks after sowing

Table 2: Summary of Statistical Analysis of Variance for the measured parameters of cowpeas

Variate	Sources of variation	Degrees of freedom	F-values	Standard Error (S.E)	Coeff.of variation (CV)
	Block	8			
	Block-Plot:				
	Treatment	4			
	Residual (Error)	32			
Depth of seed Placement (cm)			6.961*	0.331	20.8
Tap root length (cm)			0.372^{ns}	1.002	12.3
Plant height (cm)			1.588^{ns}	0.336	4.5
Stand count (cm)			3.218*	0.616	7.5
Yield (mt/ha			1.620^{ns}	0.108	18.320

* Significant at $P \leq 0.05$

ns Not significant at $P \leq 0.05$.

Effects of depth of seed placement and stand count

Averaged for all readings per treatment, Table 2 shows that the variation in the depth of seed placement and plant stand count for the different tillage treatments were significant. Paraploughing gave the greatest depth of seed placement while no tillage gave the least depth.

Result in Table 3 show that there were significant differences between treatment means for depth of seed placement and plant stand count when tested at $P \leq 0.05$.

Effects of plant height and tap root exploration

There was no significant difference in the height of plant and the depth of tap root exploration for all tillage treatmants. Statistical analysis of the data for plant height and extent of tap root exploration showed that the difference between treatment means were not significant at $P \leq 0.05$ as shown in Table 2 and 3.

Similarly, grain yield differences due to the different tillage treatments were also not significant at $P \leq 0.05$ as shown in Table 2. The difference between means for grain yield was not significant at $P \leq 0.05$ as shown in Table 3. This is in agreement with what was obtained by Maurya and Lal (1979) for maize-maize and maize-cowpea cropping sequence under minimum tillage system.

Table 3: Treatment means for the measured Parameters of cowpea[l].

Tillage Treatment	Depth of Seed placement	Stand count	Plant height 57 days after sowing (cm)	Tap root length (cm)	Yield (mt/ha)[m]
Conventional Tillage	8.089 a	23.42 b	21.94 a	23.94 a	1.58 a
Strip till shallow	4.024b	23.75 b	22.00a	25.15 a	1.65 a
Strip till deep	4.044a	26.08 a	22.89 a	23.70 a	1.89 a
Paraplough	5.049 a	25.19ab	22.47 a	24.81 a	1.77 a
No till	1.879 b	25.11ab	22.27 a	24.12 a	1.88 a

[l] Means followed by the same letter are not significantly different at P ≤ 0.05 using Duncan's new multiple range test.

[m] mt/ha = metric tonnes per hectare

CONCLUSION

Cowpea performance under different tillage systems was investigated. Soil bearing capacity was quantified by soil resistance to the penetration of a handheld cone penetrometer. Depth of seed placement, plant stand count, depth of tap root exploration, plant height and grain yield were determined.

Soil bearing capacity increased with soil depth for each tillage treatment and was least for paraploughing and conventional tillage, and was highest for shallow strip tillage and no tillage treatments. Depth of seed placement and plant stand count were highly significant for the tillage systems. Depth of tap root exploration, plant height and grain yield effects due to tillage treatments were not significant.

With the results obtained, it would be possible to select a tillage system that will optimize the performance and grain yield of cowpea.

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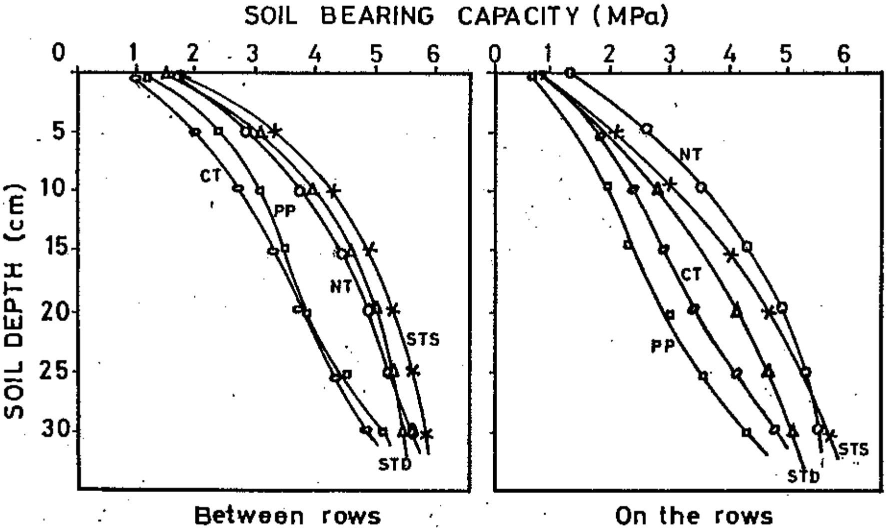

Fig.1. Soil bearing capacity vs. soil depth for tillage treatments.

CT = Conventional tillage, STS = Shallow strip tillage; STD = Deep strip tillage, PP = Paraplough; NT = No tillage.

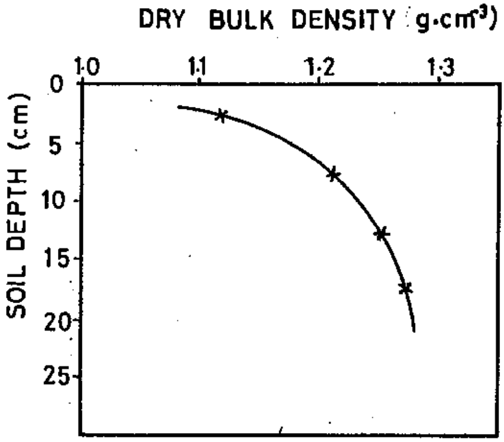

Fig. 2. Soil bulk density vs. soil depth for NT plots.

EFFECT OF DIFFERENT TILLAGE OPERATIONS ON SOIL PHYSICAL PROPERTIES, ROOT GROWTH AND THE YIELD OF RICE

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ABSTRACT

Field experiment using rice was carried out at the Bangladesh Agricultural University farmland during aman season of 1992 to study the effect of different tillage operations on soil physical properties, root growth and yield of rice in siltloam soil. The four tillage treatments were; (1) Ploughing five times by power tiller (PT_5), (2) Ploughing one time by power tiller (PT_1), (3) Ploughing five times by indigenous wooden plough with iron share (CP_5), and (4) Ploughing one time by indigenous wooden plough with iron share (CP_1). The bulk density was significantly higher in CP_1 treatment compare to other three tillage treatments. The bulk density also significantly differed between treatments and depths. The highest bulk density was recorded in 10-20 cm soil depth and the lowest value was in 0-10 cm soil depth. Similar type of results were also found in soil resistance, air-filled soil porosity and hydraulic conductivity. The PT_5 treatment produced significantly higher root mass density than that of PT_1, CP_5, CP_1 treatments. The highest root mass density was recorded at 0-20 cm depth and the lowest root mass density was recorded at 20-30 cm depth. The root mass density drastically reduced downward and significantly decreased from the top layer. There were no any significant differences in tiller number per hill and panicle length due to different tillage operations but significant differences were found in plant height and 1000 grain weight. The PT_5 treatment produced the highest grain yield compare to other three tillage treatments. There was no significant difference in straw yield due to different tillage operations.

INTRODUCTION

Differential tillage operations produce both loosening and compactive effect on soil depending on soil water and soil type. Researchers concluded that high bulk density and soil resistance restrict root penetration (Chenkual and Acharya, 1990; Sharma *et al.* 1988; and Acharya and Sood, 1992). Changes in the status of soil physical properties may impact on yield. Reports (Acharya and Sood, 1992 and Masand *et al.* 1992) indicate that high or low yields are resulted due to different tillage methods for rice cultivation.

This research study was carried out to investigate the effect of different tillage practices on soil physical properties, and consequently their effect on root growth and the yield of rice.

MATERIALS AND METHODS

Experiment using BR11 rice was carried during aman season of 1992 in the silt loam soil of the Bangladesh Agricultural University farmland.

Design and tillage methods

Randomized block design was followed with four replications. The unit plot size was 4 m x 3m keeping 1m block to block distance. Treatments consisted of 4 tillage methods: (1) Ploughing five times by power tiller (PT5) (2) Ploughing one time by power tiller (PT1) (3) Ploughing five times by indigenous wooden plough with iron share (CP5) and (4) Ploughing one time by indigenous wooden plough with iron share (CP1). The land was ploughed to a depth of about 12 cm by the above methods. The fertilizer triple super phosphate and muriate of potash were applied @ 60 and 40 kg/ha as P_2O_5 and K_2O, respectively during land preparation. Urea was added @ 80 kg N/ha in three splits such as one third during land preparation and the rest two third in two equal splits viz. at maximum tillering and before panicle initiation stage. Aman rice was planted on 6 August 1992. Row to row and plant to plant distances were maintained 25 and 20 cm apart. The crop was harvested on 8 December 1992.

Collection of root sample

Root growth was measured at maximum vegetative stage using a sampler of 7 cm in diameter. Three samples were taken from one side of a hill at 10 cm interval down to 30 cm depth. Root samples were washed out using 20 and 200 mesh sieves and dried in the laboratory under room temperature.

Soil physical characteristics

Bulk density and soil resistance were determined after harvest of rice using core sampler of known volume and pocket penetrometer, respectively at 10 cm interval down to 30 cm depth. Air-filled porosity was determined from the relationship between volume of air and total volume at vegetative growth stage. Saturated hydraulic conductivity was measured by constant head method.

RESULTS AND DISCUSSION

Bulk density

The highest soil bulk density of 1.30 gm/cm^3 was resulted in CP1 treatment and the lowest soil bulk density of 1.22 gm/cm^3 was resulted in PT5 treatment (Table 1). Incase of depth, the significant highest bulk density of 1.41 gm/cm^3 and the lowest soil density of 1.05 gm/cm^3 were found at the depths of 10-20 cm and 0-10 cm respectively. The results indicate that the soil is more loosen under PT5 treatment than that of any other treatments. Our results are in agreement with the findings of Chenkual and Acharya (1990) and Sharma *et al.* (1988).

Soil resistance

The significant highest value of soil resistance of 3.04 kg/cm^2 was measured under the CP1 treatment and the lowest value of 2.61 kg/cm^2 was measured under PT5 treatment (Table 1). The highest value of soil resistance of 3.92 kg/cm^2 was recorded at 10-20 cm soil depth and the lowest value of 1.49 kg/cm^2 was recorded at 0-10 cm soil depth (Table 1). The soil resistance abraptly increased from surface to downward upto 20 cm soil depth but there after it was decreased. Sharma *et al.* (1988) reported that the tillage intensity decreased the resistance in surface layer.

Air-filled porosity

The PT5 treatment resulted the highest air-filled porosity (1.34%) and the CP1 resulted the lowest porosity (0.92%). However, statistically atpar results were found due to PT1 and CP1 treatments (Table 1). The highest air-filled porosity of 1.54% was observed at the depth of 0-10 cm. Air-filled porosity was decreased with an increase of depth. Results indicate that more loosen soil is present under the PT5 treatment and can allow more air into the soil. Our results are supported by the finderings of SchjQnning (1989).

Table 1 Effect of different tillage operations on bulk density, soil resistance, air-filled porosity and root density of aman rice.

Treatment	Bulk density (gm/cm^3)	Soil resistance (kg/cm^2)	Air-filled porosity (%)	Root density (mg/cm^3)
<u>Tillage</u> <u>Systems</u>				
PT5	1.22	2.61	1.34	1.23
PT1	1.27	2.75	0.99	0.97
CP5	1.23	2.64	1.23	1.06
CP1	1.30	3.04	0.92	0.69
LSD(0.05)	0.01	0.23	0.12	0.11
<u>Soil</u> <u>Depth</u> <u>(cm)</u>				
0-10	1.05	1.49	1.54	2.02
10-20	1.41	3.92	1.03	0.78
20-30	1.31	2.86	0.65	0.20
LSD(0.05)	0.14	0.28	0.22	0.11

Root density

The highest root mass density of 1.23 mg/cm^3 was obtained under PT5 treatment and the lowest value of 0.69 mg/cm^3 was under CP1 treatment (Table 1). Under the PT5 treatment perhaps, the roots penetrated into the deeper layer and easily uptake nutrients from various depths which ultimately influenced their growth and development. The highest root mass density of 2.02 mg/cm^3 was resulted at 0-10 cm soil depth and the lowest one was at 20-30 cm soil depth. The root densities decreased significantly with an increase of soil depth. Our results are supported by Acharya and Sood (1992) and Ruggiers *et al.* (1990).

Saturated hydraulic conductivity

Mean value indicate that the conductivity was greater in PT5 treated plots (Table 2). The lowest mean value was found under CP1 treatment. Considering the depth, the lowest hydraulic conductivity was recorded at 10-20 cm soil depth in all treatments, probable because of high bulk density and high soil penetration resistance (Table 1). Similar results were also found by Singh *et al.* (1988) and Talsma (1985).

Table 2 Effect of different tillage operations on saturated hydraulic conductivity (cmhr^{-1}) of soil during aman season.

Soil depth (cm)	Treatments				
	PT5	PT1	CP5	CP1	Mean
0-10	33.2×10^{-3}	24.06×10^{-3}	28.78×10^{-3}	20.3×10^{-3}	28.84×10^{-3}
10-20	8.02×10^{-3}	3.72×10^{-3}	5.7×10^{-3}	3.15×10^{-3}	5.15×10^{-3}
20-30	30.6×10^{-3}	18.13×10^{-3}	24.63×10^{-3}	15.18×10^{-3}	22.14×10^{-3}
Mean	23.95×10^{-3}	15.30×10^{-3}	20.05×10^{-3}	2.87×10^{-3}	

Yield contributing characters

Tillage treatments show nonsignificant results on number of tiller/hill and panicle length. However, significant different results were found for total plant height and 1000 grain weight (Table 3). The better results are found in PT5 treatment.

Table 3 Yield and yield contributing characters under different tillage operations during aman season. Not significant:ns

Tillage Systems	Number of tiller per hill	Total plant height (cm)	Panicle length (cm)	1000 grain weight (g)	Yield (kg/ha)	
					Grain	Straw
PT5	18	103.4	24.7	26.05	5474	6628
PT1	14	92.2	23.8	24.45	4495	5191
CP5	13	99.9	24.0	25.2	4911	5873
CP1	12	96.2	23.6	23.62	3253	3607
LSD(0.05)	NS	1.99	NS	0.66	765	NS

Grain and straw yield of rice

The significantly highest grain yield of 5474 kg/ha was found in PT5 treatment and the lowest grain yield of 3253 kg/ha was found in CP1 treatment (Table 3). Again the highest straw yield was obtained under PT5 treatment. From these data it may be said that the grain and straw yields are increased due to deep tillage operations which favoured for better root growth for uptaking of water and mineral nutrients. Our results accord well with the observations obtained by Acharya and Sood (1992) and Masand *et al.* (1992).

CONCLUSION

Examination of the results indicate that the PT5 treatment was the superior one which resulted a good soil physical condition. The root mass density and the yield contributing characters were greater in the above treatment. High root mass density probably helped in increased grain and straw yields in the plots tilled by power tiller (PT5 treatment).

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Crop response to tillage and residue mulching practices in a clay soil

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Abstract

Where seasonal rainfall amount is low but of very high intensity, it is important to modify soil surface micro conditions through conventional tillage, tied ridging and residue mulching so as to dissipate raindrop energy, minimize evaporation water losses and subsequently conserve adequate soil moisture to sustain crop growth. In dryland farming areas of Kenya, these soil management practices are common and frequently result in better crop performance and yield. The performance of maize and beans under these soil management practices on a clay soil were investigated in two rainy seasons (short and long rains). The short and long rains periods received 210 mm and 408 mm of rainfall respectively.

In this experiment, crop performance (seedling emergence, crop height and ground cover) and yield were monitored periodically during the two crop growing seasons. The results obtained showed that there were significant differences at P(0.05) in seedling emergence, crop height, ground cover and yield between the treatments and the rainy seasons. Despite lagging behind in seedling emergence, crop residue mulching had better crop performance and yield than the other two tillage practices. Any variabilities in crop response between the treatments and over the two crop growing seasons were attributed to treatment differences in soil temperature and direct insolation and also to seasonal differences in the amount of rainfall. The later often resulted in soil moisture stresses during critical crop growth periods.

Introduction

In arid and semi arid (ASAL) areas of Kenya, the seasonal rainfall, though low and erratic is of very high intensity and short duration and hence is highly erosive. Rainfall impact causes surface sealing, crusting and compaction of bare soils and thus resulting in very high runoff water losses. It is this runoff water that must be harnessed and conserved in the soil *in situ* to sustain crop growth. Therefore the primary objective of any dryland farming in marginal rainfall areas should be to harvest and conserve rain water. This calls for soil management practices that not only improve rain penetration but also conserve adequate soil moisture to sustain plant growth in a crop growing season.

Conservation using among other practices contour bunds and terraces, helps to check and control surface runoff water flow. These conservation practices should be supported by systems of cultivation designed to improve rain water infiltration and storage within the soil profile (Macartney, 1970). Some of these methods include furrow diking (tied ridging), terracing, mulching and contour cultivation (Jones, 1981). In arid and semi arid areas, farming has been practised to increase infiltration and conservation of rain water (Baver et al., 1983). The use of surface mulches for instance, significantly influences the thermal properties of soil and minimizes evaporation water losses. Under marginal rainfall conditions, tillage practices developed for dryland farming aim at modifying soil physical properties to conserve soil moisture and increase yields (Stibbe and Hadas, 1977).

Soil and water conservation efforts should be seen as a priority and effective means of increasing agricultural production in semi-arid areas. In doing so, there is need for some back up research especially in such practices as conventional tillage, tied ridging, grass planting and mulching (Arnon, 1972). Some research conducted in Tanzania on tied ridges with crop residues and open ridges without crop residues showed that cereal crops on tied ridges with crop residue mulch performed better than those on open ridges without residue mulch (Jones and Mitawa, 1986). This good performance of the crop in the mulched plots was attributed to adequate conservation of soil moisture with very minimal evaporation water losses.

From the foregoing, it is evident that soil and water management interventions are primarily meant to encourage the maintenance of optimum soil moisture for good crop growth. Soil management is based on two broad practices, that is, those which help infiltration at sufficient rates and those which help to safely dispose off runoff water from the field should rainfall exceed the infiltrability of the soil (Lal, 1974). The best intervention in solving soil and water related problems in ASAL, is to develop soil management practices that can conserve both soil and moisture.

Materials and methods

A completely randomized block design with three treatments and three replicates was used in this study. Each plot 4m x 10m was enclosed by a metal sheet boundary (depth of 15 cm) with one open end on the downward side of the slope (2%) to allow free flow of runoff water. The plots were separated by 15 cm high sheet metal that prevented any runoff or soil particles from spilling over from one plot to the other. An aluminium access tube of 49 mm diameter (for monitoring soil moisture) was installed at the centre of each plot to a depth of 120 cm.

Maize stover was used on the mulch plots at a rate of 3 tonnes/ha. The mulch was applied evenly on each plot. Tied ridges had a spacing of 40 cm (as per beans row spacing) in the short rains and 75 cm (as per maize row spacing) in the long rains period. The specifications of the tied ridges were: ridge depth - 20 cm, ridge width - 15 cm, tie height - 15 cm and tie interval - 2m. One conventional tillage operation was done before planting. This tillage operation involved loosening of the top soil using forked hand hoes to a depth of 20 cm.

Two test crops, maize (variety Hybrid 614) and beans (variety Rosecoco) were planted in each of the experimental plots during the long rains and short rains periods respectively. The maize were planted during the second week of April, 1988 and took 16 weeks (upto 1st week of August, 1989) to mature. The beans were planted during the third week of November, 1988 and took 14 weeks (upto end of February) to the harvesting period. Seed densities were 450 bean and 260 maize seeds per plot. Crop performance (emergence, height and ground cover) and yield measurements were taken during the two crop growing seasons. Plant height and ground cover were measured on a weekly basis as an indication of varying rates of crop growth among the treatments.

Results and discussion

Seasonal Rainfall

The short and long rains of 1988 and 1989 (respectively) were above average when compared with the mean monthly rainfall (see Figure 1) The short rains (210 mm) were much higher than the seasonal average of 144 mm (54 years record). These rains were not evenly distributed and hence were interspersed by long dry spells of 3 weeks (one week after planting and two weeks (six weeks after planting)). The long rains (408 mm) were slightly less than the seasonal average of 418 mm with the peak rainfall months of April and May respectively. The long rains were evenly spread throughout the crop growing season.

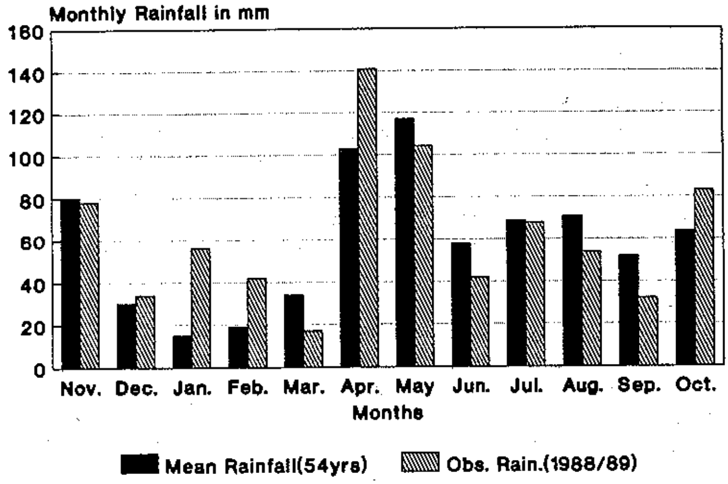

Fig. 1. Comparison of observed and mean monthly rainfall, 1988/89.

Crop Performance

During the short rains period, the average percentage of bean plants that emerged two weeks after planting were 56%, 49% and 41% in tied ridge, conventional tillage and residue mulch plots respectively. There was a significant difference between the treatments of the seedlings which emerged at P(0.05). The delay of seedling emergence in residue mulch plots was attributed to lower soil temperature as has been observed in experiments elsewhere (Donahue et al., 1983). Murray and Lal, (1977) observed high temperatures under mulch.

At the harvesting stage, the average number of plants which germinated in each plot were determined and found to be 50%, 49% and 44% for the tied ridge, conventional tillage and residue mulch plots. The 3% increase in plants in residue mulch plots compared to the two weeks measurement was attributed to late emergence. The decrease in plant population especially that observed in tied ridge plots, was attributed to insect infestation during the crop growing period.

Plant height measurements showed that residue mulch had somewhat taller plants than the other two treatments from the fourth to the eleventh week after planting (see Figure 1). There was no significant difference of the heights between the treatments throughout the crop growing period except at the tenth and eleventh weeks where there was some significant difference at P (0.05). Plant height is often used as a measure of vegetative growth which sometimes reflects on the amount of moisture available to the crop (Murray and Lal, 1977).

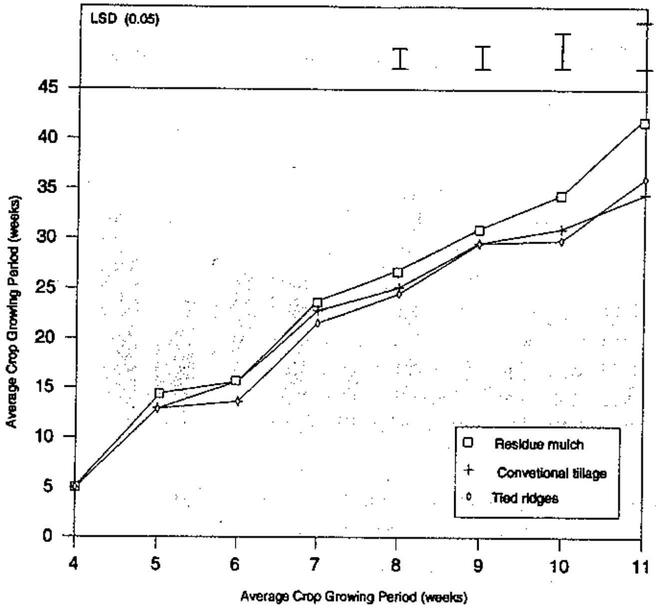

Fig. 2. Average crop height of beans, short rains period, 1988 (Gicheru, 1990).

Percent crop canopy cover (of beans) for residue mulch, conventional tillage and tied ridge plots increased from 8%, 13% and 22% in the fourth week after planting to a maximum of 55%, 53% and 50% during the tenth week after planting (see Figure 3). The high initial canopy cover was due to good seedling emergence after planting. There was a decrease of canopy cover in all the treatments when the crop reached the maturity stage at 14 weeks due to shrinkage and falling of dry leaves.

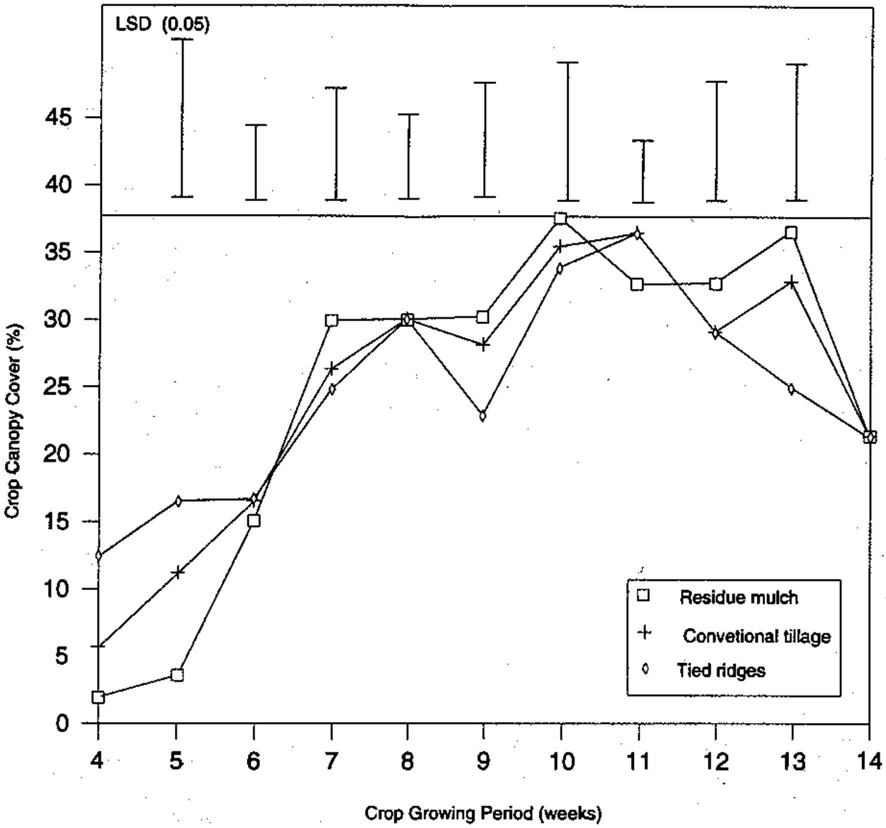

Fig. 3. Canopy cover development for beans, short rains period, 1988 (Gicheru, 1990).

Over the long rains period, average maize seedling emergence was 72%, 87% and 83% for tied ridge, conventional tillage and residue mulch plots respectively. The poor seedling emergence in tied ridge plots was attributed to desiccation of the seeds due to high insolation (high temperatures) as the seeds were dry planted on the shoulders of the ridges.

Crop heights were similar in all the treatments from emergence (two weeks after planting) upto the seventh week after planting (see Figure 4). Tied ridge plots had the shortest plants throughout the crop growing season. After the eleventh week, visual observation of crop performance showed some moisture stress in all the treatments. This effect was more pronounced in tied ridge plots than in the other two treatments. The significant differences at P(0.05) in crop heights among the treatments that occurred after the eleventh week was due to the significant soil moisture differences in the soil profiles of the three treatments. The maize plants in the conventional tillage and residue mulch plots tasselled earlier than those in the tied ridge plots. This long vegetative growth in the latter plots was attributed to moisture stress.

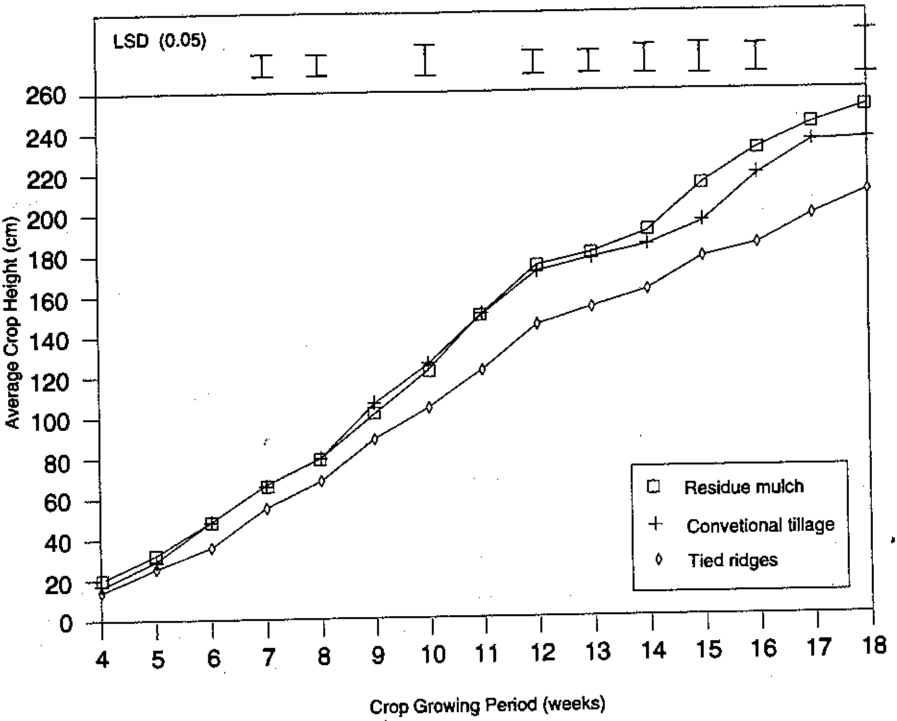

Fig. 4. Average crop height for maize, long rains period, 1989 (Gicheru, 1990).

Percent crop canopy cover (of maize) for residue mulch, conventional tillage and tied ridge plots increased from 15% in all the treatments four weeks after planting to 75%, 73% and 55% respectively, sixteen weeks after planting (see Figure 5). Maximum canopy cover was observed in the tenth week after planting and then it decreased gradually thereafter. Canopy cover was low in all the treatments at the eleventh week because of some moisture stress that caused the wilting of the crop. At the thirteenth week after planting, the crop had reached the ripening stage and hence there was a decrease in crop canopy cover due to leaf fall and shrinkage.

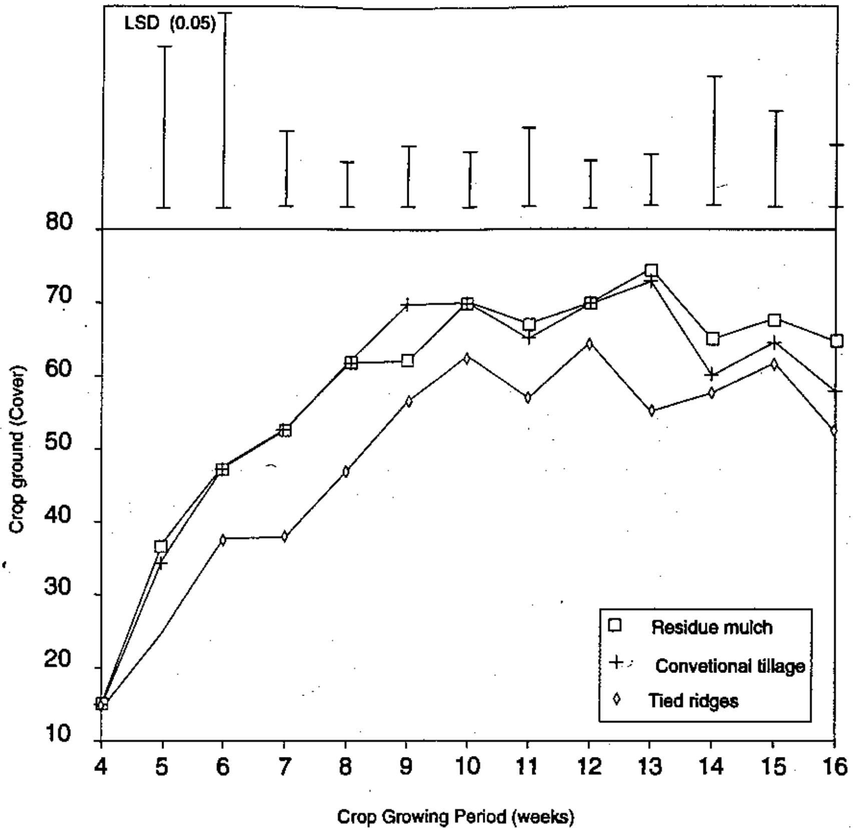

Fig. 5. Canopy cover development of maize, long rains period, 1989 (Gicheru, 1990).

Crop Yields

Results obtained from this experimental study showed that there existed a relationship between crop height and yield between the treatments. Residue mulch and conventional tillage plots, which had the tallest plants, had more grain yields than tied ridge plots (see Table 1).

Table 1.

Average grain yields of maize and beans, 1988 and 1989 (Gicheru, 1990)

Crop	Average grain yield (Kg/ha)		
	Residue mulch	Conventional tillage	Tied ridging
Maize	1083.3	850.0	833.3
Beans	936.1	922.2	683.3

Conclusions

Crop performance (emergence, height, vegetative growth and yield) for both rain periods showed that residue mulching is the most appropriate soil management practice for the ferric Acrisol at Kalalu, Laikipia. The good performance of the test crops under residue mulch treatments was believed to have contributed to the low seasonal moisture content observed in these plots. Thus it was very evident that the crops under residue mulch extracted more moisture from the soil profile. The contribution of conserved moisture to crop performance and yield was more significant in residue mulch than in the other treatments.

Over the two crop growing seasons, seedling emergence, crop height and canopy cover varied with the test crop. For instance, the canopy cover under the bean crop in the short rains period, showed significant treatment differences over the first five weeks after planting. In this period, residue mulch had the least cover which was attributed to the delay in seedling emergence. For the same period during the long rains season, the maize crop had no significant differences in canopy cover for the three treatments. In the long rains period, some significant treatment differences in canopy cover were observed in the seventh week after planting. This was attributed to availability of adequate moisture from the peak rainfall in April (141 mm) and May (104 mm).

During the experimental period, there were significant differences between the treatments (in both ANOVA and LSD) in crop height and yield at P(0.05) for each of the two test crops. The beans crop experienced long dry spells of 3 weeks (one week after planting) and another 2 weeks(6 weeks after planting). These were critical crop growth periods and hence could have reduced crop yield. The maize crop however, received ample and evenly distributed rainfall and hence the good performance of the crop through the season.

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EFFECT OF TILLAGE ON MAIZE YIELD IN THREE VALLEY BOTTOMS IN HUMID TROPICAL SOUTHWESTERN NIGERIA

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ABSTRACT

The study was conducted to evaluate the effect of different tillage methods and fertilizer on maize yield in three high (WT1), medium (WT2), and low (WT3) water table sites. Tillage consisted of flat-no-till, mound-till and ridge-till, while fertilizer was either applied or not.

Air-filled porosity of the top 30cm of the soil averaged over all seasons and sites was significantly affected (P=0.01) by tillage. The highest value was obtained in the MT plots which was 49.3% and 37.8% greater than the NT and RT systems, respectively, and indicate better air-water relationships in the MT system.

Tillage significantly affected green maize yield in 1989/90. Mound-till out-yielded NT and RT by 19.5 and 28.8% (P=0.05) in WT2 and 29.9 and 29.6% (P=0.01) in WT3. In 1990 and 1990/91, the yield differences (P=0.05) over the fertilized and control plots of the NT and RT averaged over the three locations were 21.5 and 21.8% and 12.2 and 28.2%, respectively.

Total N content of the top 30cm at planting and at harvest was 0.11 and 0.20%, 0.24 and 0.19%, and 0.04 and 0.19% at zero level of applied N in WT1, WT2 and WT3 respectively, indicating increased N mineralization in the soils. The mound-till with fertilizer appeared to be suitable in sustaining maize production in the valley bottoms.

INTRODUCTION

The inland valley bottoms of Southwestern Nigeria are a category of wetlands[1]. The soils are influenced by seasonal or perennially high groundwater tables (WT), and are poorly drained. Poor drainage severely limits field cultural activities, and restrict crop growth[2]. Severe yield depressions are observed when upland crops are grown on wetlands[3]. Poor crop growth is also caused by low availability and inhibited uptake of nitrogen and other essential nutrients[4].

Farmers overcome the drainage-induced constraint by constructing mounds and ridges[5]. Reports from Southwestern Ohio[6] showed that greater maize (Zea mays L.) grain yield was obtained when maize was planted on raised beds, compared with a non-elevated seedbed on a poorly drained Clermount silt loam. Comparable results for maize were also obtained in Ohio[7].

Positive responses have heen obtained with raised seedbeds in poorly drained soils in Southwestern Nigeria. However the relative suitability of the seedbeds has not been evaluated. This study was conducted to evaluate the effect of mounds and ridges, with and without fertilizer on maize yield in three wetland soils.

MATERIALS AND METHODS

Three tillage experiments were conducted in 1989/90, 1990, and 1990/91 dry, wet, and dry seasons in three high (<40cm, WT1), medium (40-70cm,WT2), and low (>70cm, WT3) water-table sites located at Bolude, Adekola and Arikoko villages in humid Southwestern Nigeria (07°2'N, 04°2'E). The mean annual rainfall for the area is about 1500 mm. The distribution is bimodal, with wet (April - October) and dry (November - March) seasons. The soils at the experimental locations are derived from Basement Complex rocks, and are classified as Tropic Fluvaquent, Aquic Ustifluvent, and Aquic Ustifluvent, respectively. Soil physical and chemical properties of the top 30cm are summarized in Table 4.

The seedbed preparation methods used were no-tillage (NT), mounds (MT), (60cm diameter, 45cm high, 14 mounds x 12 rows per plot), and ridges (RT) (60cm wide, 45cm high, 12 per plot) (using hand-hoe cultivation). In 1990 and 1990/91, the mounds and ridges were recultivated. The experimental design was split plot arranged as randomized complete blocks, with tillage in main plots and fertilizer in subplots. Plot size was 10m x 8.4m.

Maize (TZESR-Y) was sown at a plant population of 20,000 plants/ha in all plots. Plant spacing of 70 x 70cm was used. Fertilizer was applied at the rate of 45 kgN/ha, 2 kgP/ha, and 16 kgK/ha in WT1, 45 kgN/ha, 9 kgP/ha and 39 kgK/ha in WT2, and 84 kgN/ha, 18 kgP/ha, and 31 kgK/ha in WT3 at planting, and an extra 30 kg urea/ha at tasseling, throughout the experiments. In 1989/90 and 1990/91, all plots were mulched at the rate of 4.2 t/ha. Weeds were controlled by slashing.

Soil moisture content was measured at regular intervals with a neutron moisture meter at depth intervals of 0-10, 10-20, and 20-30cm, in access tubes installed in two adjacent fertilized and not-fertilized subplots. Air-filled porosity was calculated from volumetric soil moisture values. Depth to water table was measured in auger-hole transects midway in the experimental area at regular intervals.

RESULTS AND DISCUSSION

Water table depth

Depth to WT during 1989/90 was highest in WT1 (28.3cm) and lowest in WT3 (120.0cm) (Fig. 1a). The decrease in WT depth was due to lack of rain, increased solar radiation, and rise in temperature which enhanced evapotranspiration characteristic of this period. The persistence of shallow WT in 1990 and 1990/91 (Fig. 1b and c) particularly at WT1 and WT2 indicates the prevalence of anaerobic conditions in the crop rooting zone.

Tillage effects on soil moisture

The volumetric moisture content in relation to the tillage systems is shown in Table 1a and b. Significantly higher soil moisture contents (P=0.01) were obtained in the NT and the least in the MT. Averaged over the three seasons and locations, the increases over the MT and RT plots were 28.8% and 16.6% in the NT plots. The much lower moisture regime in the MT compared with the NT and RT is associated with a greater evaporating surface provided by the isolated mound, but while advantageous in the wet season in terms of better aeration in the crop rooting zone, soil moisture conservation will be required in dry season crop production.

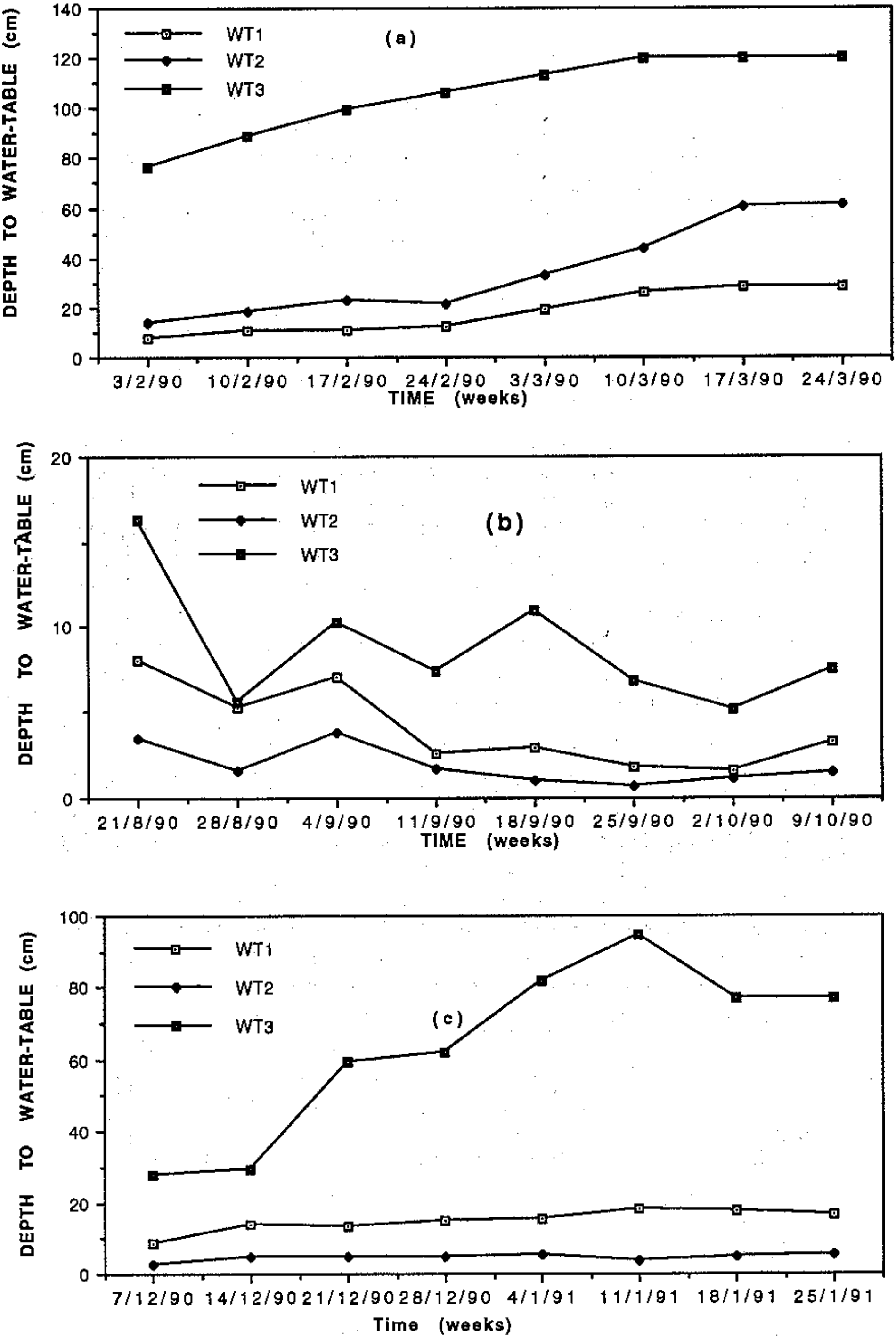

Fig. 1: Variation in depth of water table in WT1, WT2 and WT3 during (a) 1989/90 dry, (b) 1990 wet and (c) 1990/91 dry seasons.

Table 1a: Soil moisture content as influenced by season and tillage in WT1, WT2 and WT3

	Tillage		
Season	NT	MT	RT
1989/90	0.385	0.361	0.390
1990	0.469	0.344	0.386
1990/91	0.411	0.194	0.302
$LSD_{<.01}$ =	0.054 $cm^3\ cm^{-3}$		

Table 1b: Soil moisture content as influenced by site and tillage in 1989/90 dry, 1990 wet and 1990/91 dry seasons

	Tillage		
Site	NT	MT	RT
WT1	0.461	0.327	0.442
WT2	0.498	0.283	0.389
WT3	0.305	0.289	0.248
$LSD_{<.01}$ =	0.054 $cm^3\ cm^{-3}$		

Tillage effects on air-field porosity

Air-filled porosity of the top 30cm of the soil was significantly influenced (P=0.01) by tillage in all seasons and sites (Table 2a and b). The highest values were obtained in the MT system and the increases over the NT and RT plots were 10.0% and 22.8% in 1989/90, 55.6% and 29.9% in 1990, and 67.6% and 52.0% in 1990/91. The relative performance of the MT generally and in particular in 1990 wet season and in the high WT valley bottom point out the suitability of the MT method in controlling the ground WT and improving aeration in the topsoil layers.

Table 2a: Air-filled porosity as influenced by season and tillage WT1, WT2 and WT3

	Tillage		
Season	NT	MT	RT
1989/90	0.197	0.219	0.169
1990	0.119	0.268	0.188
1990/91	0.122	0.377	0.181
$LSD_{<.01}$ =	0.053 $cm^3\ cm^{-3}$		

Table 2b: Air-filled porosity as influenced by site and tillage in 1989/90 dry, 1990 wet and 1990/91 dry seasons

	Tillage		
Site	NT	MT	RT
WT1	0.138	0.297	0.183
WT2	0.124	0.325	0.146
WT3	0.175	0.242	0.208
LSD $_{<.01}$ =	0.053 $cm^3\ cm^{-3}$		

Tillage and fertilizer effects on yields

Green maize yield (Table 3) was significantly influenced by tillage in WT2 (P=0.05) and WT3 (P=0.01) in 1989/90. The highest yields were obtained in the MT compared with the NT and RT plots. The increases over the NT and RT were 19.5% and 8.8%, and 29.9% and 29.6% in the MT in WT2 and WT3, respectively. Tillage and fertilizer treatments averaged over the three sites had a significant effect (P=0.05) on green maize yield (Table 3), in 1990 and 1990/91. The highest yields were obtained in the MT plots. The yield increases over the fertilized and control plots in NT and RT were 21.5 and 21.8% and 12.2 and 28.2% in the MT plots. The performance of the MT compared with NT and RT could be due to better air-water relationships, root growth and nutrient absorption in the soil. Results suggest that the MT system is a suitable tillage practice for controlling the WT and sustain maize production in the valley bottoms.

Table 3a: Green maize yield in different tillage systems (1989/90)

	Tillage		
Site	NT	MT	RT
WT2	3.13	3.89	2.77
LSD <.05 =	.70 t/ha		
WT3	2.72	3.88	2.73
LSD <.01 =	9.8 t/ha		

Table 3b: Green maize yield in different tillage and fertilizer treatments at WT1, WT2, WT3 in 1990 wet and 1990/91 dry seasons

	Tillage		
Site	NT	MT	RT
F_0	1.69	2.16	1.55
F	2.96	3.77	3.31
LSD <.05 =	3.8 t/ha		

Fo = not fertilized, F = fertilized

Soil physical property and nutrient levels

Texture of the soils (Table 4) was not affected by tillage indicating negligible clay elluviation in the soils. Tillage did not affect soil pH (Table 4), probably due to influx of exchangeable cations[8]. ECEC in both fertilized and control plots was adversely affected by tillage methods. Organic C and N contents were generally high among fertilizer and tillage treatments. Increases in organic C is associated with increased soil biomass[9] and smaller rate of mineralization[10]. The increases in N levels at zero level of applied N in both tilled and untilled plots are attributed to N mineralization and less leaching loss of mineralized N in the soils[8] indicating that reports by[11] may not always be true. Available P at harvest was much less than at planting and was the most deficient nutrient in the soils. There is need for nutrient supplementation to sustain crop production in the valley bottoms.

CONCLUSION

Tillage had a significant effect on soil moisture content and air-filled porosity but the greater effects were in MT than in NT and RT systems. Tillage and fertilizer significantly influenced green maize yield with the MT out-yielding the NT and RT methods. Organic C and N contents of the soils increased with tillage at the end of the experiments. MT with fertilizer appears a more suitable tillage practice than NT and RT for controlling the WT in crop production in the bottomland soils in both wet and dry seasons.

Table 4: Some physical property and nutrient levels of soils at experimental sites.

Parameter	Planting			HARVEST WT1			HARVEST WT2			HARVEST WT3		
	WT1	WT2	WT3	NT	MT	RT	NT	MT	RT	NT	MT	RT
Physical (0-30cm soil depth)												
Texture	L	CL	SCL	CL	CL	CL	CL	CL	CL	CL	CL	CL
Chemical (0-30cm soil depth)												
Organic C (%)	1.30	2.78	0.37	Fo 2.21	2.10	2.10	2.14	2.09	2.13	2.22	2.15	2.14
				Fo 1.72	1.76	2.30	2.90	2.83	1.73	1.39	1.15	1.44
Total N (%)	0.11	0.24	0.04	Fo 0.20	0.20	0.19	0.19	0.19	0.19	0.19	0.19	0.19
				Fo 0.15	0.19	0.21	0.25	0.24	0.17	0.12	0.12	0.14
Bray available P (µg/g)	14.04	10.61	6.18	Fo 5.64	5.78	5.75	5.91	5.71	6.02	6.25	6.29	6.16
				F 7.26	7.39	6.39	5.48	5.38	6.12	5.53	5.84	5.98
Exchangeable K (meq/100g)	0.18	0.15	0.16	Fo 0.36	0.34	0.37	0.38	0.38	0.45	0.54	0.53	0.49
				F 0.35	0.35	0.35	0.36	0.34	0.31	0.24	0.26	0.28
ECEC (meq/100g)	14.77	10.42	11.60	Fo 8.75	8.46	8.46	8.63	8.40	7.93	6.96	7.38	7.67
(neutral normal NH4OAC method)				F 9.01	8.74	8.80	6.96	8.84	7.63	6.02	6.44	7.04
pH (H20)	7.0	6.3	6.7	Fo 6.9	6.9	6.9	6.8	6.9	6.9	7.2	7.0	7.0
				F 6.7	6.8	6.9	6.9	7.8	6.9	7.2	7.1	7.0

L = Loam; SL = Sandy loam; SCL = Sandy clay loam; CL = Clay loam; NT = No-tillage; MT = Mound tillage; RT = Ridge tillage; Fo = Not-fertilized; F = Fertilized.

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EFFECT OF MULCH AND NITROGEN FERTILIZER UNDER A ZERO TILLAGE SYSTEM ON MAIZE (Zea mays L.) GROWTH AND YIELD

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ABSTRACT

The effect of mulching and N fertilization under a zero tillage system on maize growth and yield in an Oxic Paleustalf at Mokwa (Lat. 90°18'N, and Long. 05°04'E) in the Southern Guinea Savanna region of Nigeria was investigated over three cropping seasons. Three rates of mulch (0, 5 and 10 t ha^{-1}) as main plots and five rates of N fertilizer (0, 30, 60, 90 and 120 kg ha^{-1}) as subplots were arranged in split plot design. Grain yield and plant height were significantly increased ($P = 0.05$) by mulching and N fertilization. Mulching significantly ($P = 0.05$) suppressed weed growth whereas weed growth significantly increased with increasing levels of N. The interaction effect between mulch and N fertilizer was also significant. Mulching and N fertilization had no effect on leaf concentrations of P, K, Ca, and Mg while the main interaction effects on leaf N were significant. Root density increased with increasing rates of mulch and N fertilizers.

This study indicates a strong advantage of application of mulch on maize performance and yield in this light textured soil of the Nigerian savanna.

INTRODUCTION

The zero tillage system of soil management in which residue is left as mulch has been reported as having great potential for maintaining the productivity of some tropical soils by reducing soil erosion, preserving soil structure, soil organic matter, water holding capacity and soil nutrient status (1, 2, 3 and 4). These benefits have been largely attributed to the residues left as mulch which acts as a physical barrier to rain and gradually decays to form organic matter in the upper soil profile. Weed growth is reported to be considerably reduced under mulch (5) resulting in increased yield. Okigbo (6 and 7) demonstrated the beneficial effects of mulch in increasing yield on an Ultisol. Similar results have been demonstrated for some Alfisols (8). Although yield increases are frequently obtained when residues are used as mulch, the priority problem may be the kind of fertilizer response, especially N fertilizer, that may be obtained under such a management system.

Considerable research on fertilizer response under conventional and zero tillage systems has been conducted in temperate regions. In the tropics most fertilizer trials have dealt with conventional tillage. Fertilizer use efficiency with zero tillage system remains a controversial issue. Bandel et al. (9) reported N deficiency on zero tillage plots even at recommended levels of N. Lal (10) noted that at the initial stages of adopting zero tillage, the N requirement was generally more than with conventional tillage systems.

Low fertilizer use efficiency with the zero tillage system has been attributed to high weed competition (11 and 12), low response due to microbial competition (13 and 14). Jack et al. and Jurion and Henry (16) found that in addition to differences in physical factors and availability of nutrients, the fertilizer response in mulched soil can differ significantly from that in unmulched soil due to complex physicochemical and biological factors and that yield differences may be expected.

Studies were, therefore, carried out on an Alfisol at Mokwa in the Southern Guinea Savanna region of Nigeria to investigate the effect of mulching and N fertilizer under a zero tillage system on maize growth and grain yield.

MATERIALS AND METHODS

The experiment was conducted from 1982 to 1984 at the research farm of the Agricultural Research Station, Mokwa (Latitude 09°18'N, and Longitude 05°04'), Institute for Agricultural Research, Ahmadu Bello University, Zaria. The soil is classified as Alfisol (Paleustalf) derived from the Nupe Sand stone parent material. The texture of the surface layer of the experimental site is sandy loam changing into clay loam to clay in the subsurface horizon. The mean annual rainfall at the experimental area is 1055 mm with a unimodal rainy period varying from 5 to 6 months (May-October).

The treatments consisted of three mulch rates 0, 5 and 10 t ha^{-1}) as main plots and five N fertilizer rates (0, 30, 60, 90 and 120 kg ha^{-1}) as subplots arranged in a split plot design with four replications. Calcium ammonium nitrate (CAN) was the N source. Being a zero tillage system, weeds were manually slashed and cleared from the field a week before paraquat (1-1-dimethyl 4, 4-bipyridy-nium) was applied at the rate of 1.0 kg (active ingredient)/ha to kill weed regrowths. All plots (4 x 6 m, with 1m border), received 26 kg P ha^{-1} as single super phosphate (SSP) and 50 kg K ha^{-1} as muriate of potash (MOP) applied by surface broadcast. One third of the N fertilizer was applied to appropriate plots along with the SSP and MOP at planting while the remaining two thirds was applied at 4 weeks after planting (WAP) by banding. Maize (Var. TZPB) was planted after being dressed with Aldrex T. Three seeds were planted manually at 75 cm between and 25 cm within row spacing giving a plant population of 53,300 plants ha^{-1}. The plants were thinned down to one per hill at 2 WAP. The plant residue of dry Gamba (Andropogon gayanus) used as the mulching material was immediately spread on the surface of appropriate plots.

The number of maize seedlings that emerged at about eight days after planting (DAP) were counted and computed as the percentage of the number of seeds planted per experimental unit. Height measurements were taken at two weekly intervals. Ten stands within the four inner rows were measured and mean values calculated for each plot. Weed population was determined as weed scores on a scale of 0 (min) and 5 (max) at 30 DAP. Ear leaf samples were collected at about 50% silking growth stage, washed with water and oven dried at 65°C to constant weight. The samples were ground and analysed for N, P, K, Ca and Mg as described by (17). At the same growth stage, root samples were collected by excavating soil blocks 10 cm wide by 10 cm length (in the 0-10

Table 1. Effects of mulch and N fertilizer on percentage emergence of maize seedlings

N rate (kg ha^{-1})	Mulch rate (t ha^{-1}) 1982				1983				1984			
	0	5	10	Mean	0	5	10	Mean	0	5	10	Mean
0	80.5	90.3	86.5	85.8	92.0	90.3	89.3	90.6	90.5	86.0	85.3	87.3
30	83.8	85.5	86.0	85.1	90.8	92.5	90.3	91.2	81.8	83.0	83.8	82.9
60	84.3	87.0	90.0	87.1	91.8	89.8	91.0	90.9	81.0	84.0	85.3	83.4
90	87.5	87.0	90.0	88.2	90.3	93.5	93.0	92.3	86.0	87.0	87.3	96.8
120	85.0	88.8	88.8	87.5	88.8	95.0	92.5	92.1	86.5	88.8	87.8	87.7
Mean	84.2	87.7	88.3		90.7	92.2	92.3		85.2	85.8	85.9	
LSD (0.05)												
Mulch (M)			ns			ns				ns		
Fertilizer (F)			ns			ns				ns		
M x F			ns			ns				ns		

cm depth) on all mulch treatments and the 0, 60 and 120 kg N/ha treatments during the 1982 and 1983 cropping seasons. Each block was put into a 2 mm sieve and washed under a gentle running tap water to remove all soils and organic particles. The roots remaining were placed in an envelope oven-dried at 65°C to constant weight. Grain yields were determined at 12% moisture content.

Basic analysis of variance to account for the effects of mulch and N fertilizers (treatment effects) was made according to the experimental design proposed

RESULTS AND DISCUSSION

Effect on seedling emergence, plant height, root density and weed growth

Seedling emergence was not significantly affected by mulching and N fertilization in all seasons, averaging 86.7, 91.7 and 85.6 for 1982, 1983 and 1984 respectively (Table 1). Emergence, however, was slightly more with 2 to 4% in mulched than unmulched plots probably due to improved soil moisture and temperature regimes under mulch.

Plant height is often taken as an indication of plant vigor. Plant height measurements taken at 48 and 75 DAP showed that at both stages of growth, mulching and N fertilization significantly increased plant height (Table 2). The effect of mulching may be due to improved moisture and temperature regimes. Greater root density (Fig. 1) resulting in better nutrient absorption and reduced competition for plant nutrients may have also contributed to taller plants in the mulched plots.

Table 2. Effect of mulch and N fertilizer on maize plant height (cm) taken at 48 and 75 DAP in 1983.

N rate (kg ha^{-1})	Mulch rate (t ha^{-1})					
	0		5		10	
	48	75	48	75	48	75
0	88.5	192.6	80.3	207.8	89.7	202.2
30	88.4	203.1	87.7	211.5	98.3	229.1
60	107.3	228.6	116.5	230.4	117.4	239.8
90	128.4	231.0	140.1	251.9	145.1	250.3
120	131.2	238.6	144.7	258.9	141.5	258.6
LSD (0.05)						
Mulch (M)	6.6	11.6				
Fertilizer (F)	7.1	12.4				
M x F	ns	ns				

Root density increased with increasing rates of mulch and N fertilizer (Fig. 1). The interaction effect was obvious as the increase due to mulch rates became more pronounced at higher rates of N fertilizer.

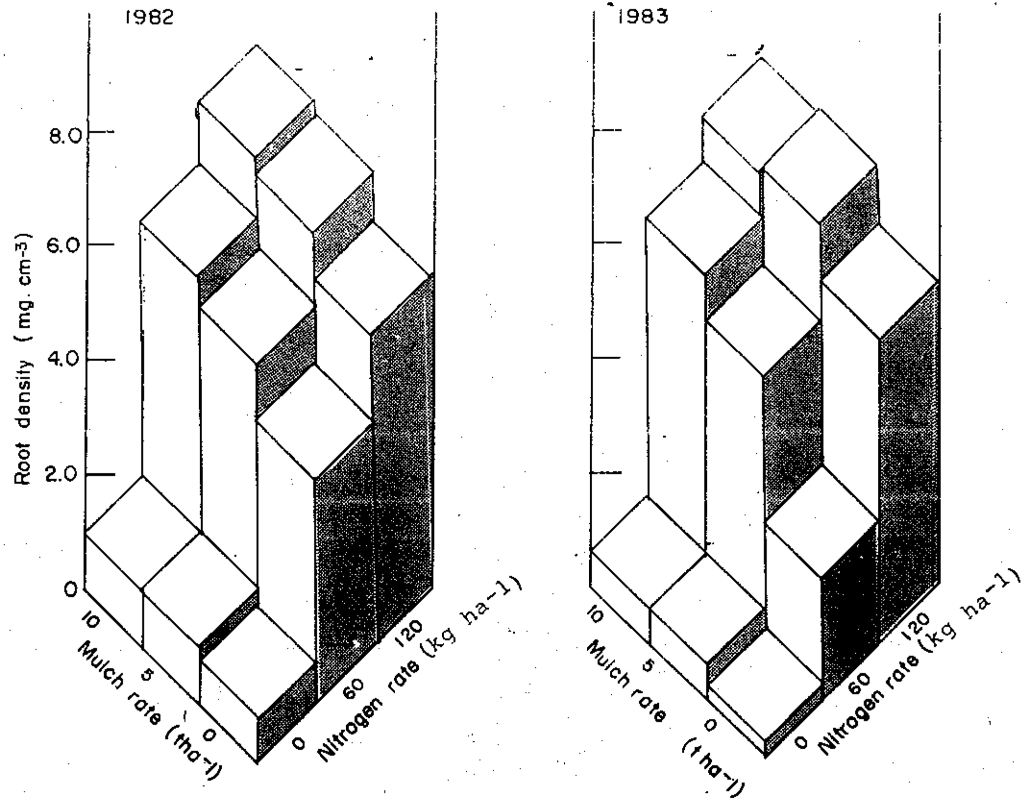

Figure 1 , Effect of mulching and nitrogen fertilization on root density.

Table 3. Effect of mulch and N fertilizer on weed growth

N rate (kg ha^{-1})	Weed score											
	Mulch rates (t ha^{-1})											
	1982				1983				1984			
	0	5	10	Mean	0	5	10	Mean	0	5	10	Mean
0	0.54	0.18	0.23	0.32	0.50	0.19	0.13	0.27	0.59	0.44	0.19	0.41
30	0.53	0.25	0.31	0.36	0.35	0.13	0.25	0.24	0.59	0.65	0.38	0.54
60	0.90	0.54	0.59	0.68	0.75	0.13	0.51	0.46	1.03	0.60	0.54	0.72
90	1.00	0.60	0.73	0.78	1.05	0.40	0.65	0.70	1.40	0.63	0.75	0.93
120	1.25	0.60	0.50	0.78	0.99	0.59	0.61	0.73	1.50	0.64	0.61	0.92
Mean	0.84	0.43	0.47		0.73	0.29	0.43		1.02	0.59	0.49	
LSD (0.05)												
Mulch (M)		0.18				0.21				0.11		
Fertilizer		0.166				0.14				0.14		
M x F		ns				ns				0.27		

Table 4. Effect of mulch and N fertilizer on nutrient concentration (%) in maize earleaves sampled at initial silk stage in 1983.

N rate (kg ha^{-1})	Mulch rate (t ha^{-1})														
	0					5					10				
	N	P	K	Ca	Mg	N	P	K	Ca	Mg	N	P	K	Ca	Mg
0	2.23	0.20	2.20	0.40	0.28	1.58	0.21	2.28	0.43	0.27	1.48	0.20	2.20	0.41	0.30
30	2.35	0.22	2.03	0.52	0.35	2.07	0.23	2.27	0.40	0.29	2.62	0.26	2.67	0.45	0.27
60	2.63	0.25	2.27	0.54	0.36	2.38	0.25	2.35	0.48	0.33	2.63	0.23	2.16	0.45	0.31
90	2.92	0.28	2.26	0.48	0.36	2.69	0.26	0.30	0.54	0.34	2.64	0.28	2.51	0.50	0.31
120	2.81	0.25	2.08	0.49	0.36	2.91	0.30	2.59	0.46	0.29	2.66	0.28	2.42	0.46	0.26
Mean	2.59	0.24	2.17	0.49	0.34	2.34	0.25	2.34	0.49	0.30	2.41	0.25	2.39	0.45	0.29
LSD (0.05)															
Mulch (M)	0.16	ns	ns	ns	ns										
Fertilizer (f)	0.18	ns	0.02	ns	ns										
Interaction															
M x F	0.31	ns	ns	ns	ns										

In all seasons, weed growth was significantly reduced by mulching, confirming the effectiveness of mulch in suppressing weed growth provided there is adequate soil cover. There was a significant but negative correlation ($r = 0.45$) between mulch rate and weed growth (Table 6). Weed growth significantly increased with increasing rate of N (Table 3).

Effect on nutrient concentration in ear leaf

The concentration of nutrients in the ear leaf is shown in Table 4. Leaf N concentration was significantly affected by mulching and N fertilizer. The interaction effects were also significant. Leaf concentrations of P, K, Ca, and Mg were not affected by both treatments. Potassium concentration, however, tended to increase while Ca and Mg concentrations decreased with increasing mulch rates. This may be due to the antagonistic effect of K on Ca and Mg uptake in monocotyledons (18). Nitrogen concentration in leaves of plants on mulched plots were generally lower than on unmulched plots. Since plant vigor on mulched plots was better than on unmulched plots, the decreased N concentration on the latter plots may be due to dilution effect and also probably to immobilization on nitrogen by the residue. Ear leaf concentrations of all the nutrients increased with increasing N fertilizer rates probably due to higher absorbing capacity of roots in these plots. Lal (19) reported increases in leaf N and K with increasing N fertilizer rates.

Effects on grain yield

Grain yield as influenced by mulching and N fertilizer treatments is shown in Table 5. Both treatments significantly increased yield in 1983 and 1984 whereas in 1982 yield was significantly increased by N fertilizer alone. There were no significant differences between the 5 and 10 t ha^{-1} mulch rates. The effect of mulching on crop yield is an integrated effect of several factors. Studies carried out elsewhere have shown that the benefits of mulching are mainly due to improved moisture conservation, lower soil temperatures at the seedling stage, lower bulk density and penetrometer resistance and, suppression of weed growth (8, 20 and 21). These factors may have been responsible for the increased yield under mulch. It may have also been due to decreased losses in surface soil and plant nutrients under mulch. Soil and nutrients losses due to water erosion can have adverse effects on crop yield particularly if unchecked (2). The significant yield increase with increasing levels of N fertilizer is expected. Native N in the soils of the study area is inherently low with the result that cereal crops which have high demands for N respond strongly to N fertilizer. Simple correlations among some parameters (Table 6) indicated that grain yield correlated significantly with N fertilizer ($r = 0.81$), plant height at different growth states and percentage N and Ca in the ear leaf.

CONCLUSION

This study indicates a strong advantage of applications of mulch on crop performance and yield in this light textured soil of the Nigerian savanna. The results also suggest that the use of fertilizer N under mulch without tillage is important if optimum yields are to be obtained. There are, however, some problems associated with the use of mulch. Effective control of termites is necessary to achieve the maximum benefits from

Table 5. Effects of mulch and N fertilizer on maize grain yield (kg ha^{-1})

N rate (kg ha^{-1})	Mulch rate (t ha^{-1}) 1982				1983				1984			
	0	5	10	Mean	0	5	10	Mean	0	5	10	Mean
0	1489	1403	1423	1438	1702	1692	1742	1712	311	827	631	590
30	2521	2537	3253	2770	2149	2591	3101	2614	569	1492	1533	1198
60	4302	3943	3691	3979	3092	3520	3419	3344	2054	1996	2293	2114
90	5249	5496	4897	5214	4632	5282	5604	5173	3179	3485	3533	3399
120	5945	5987	5649	5860	4321	5658	5840	5273	3338	3721	3695	3585
Mean	3901	3873	3782		3149	3749	3941		1890	2304	2337	
LSD (0.05)												
Mulch (M)		ns				549				398		
Fertilizer (F)		605				392				380		
M x F		ns				ns				ns		

mulching. The other problems include the risk of carry-over of insect pests, lack of availability of suitable mulch materials and the sometimes uneconomical nature of the operation. The importance of weed control in these light textured soils cannot be overemphasized. Weeds present a formidable obstacle to crop production through their strong competition for most factors of crop growth. This study demonstrates the effectiveness of mulching in decreasing weed competition even in fertilized fields.

Table 6. Simple correlations among some parameters

Dependent Variable	Independent Variable	
Grain yield (kg/ha)	Plant height at 48 DAP	0.83*
	Plant height at 75 DAP	0.76**
	N fertilizer level	0.81**
	% N in Earleaf	0.73**
	% Ca in Earleaf	0.62**
	N fertilizer level	0.63**
Plant height (cm)	N fertilizer level	0.55**
Weed growth score	Crop residue Mulch	-0.45

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TILLAGE PRACTICES UNDER IRRIGATED AGRICULTURE IN THE SOKOTO STATE OF NIGERIA.

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ABSTRACT:

Traditional tillage practices under large and small scale irrigation projects and tillage research findings under irrigated agriculture are discussed in the paper. The evolution of the different kinds of tillage system to suit the small land holding conditions is also discussed. Comparisons of various tillage systems on the irrigated soils under formal irrigation project have shown as much variability from study to study as in non-irrigated soils. Probably the major reason for this observed variability is intensity of crop cultivation, type of soil, size of the land holding and irrigation system, and the micro-climate of the project. The combination of shallow and no-tillage in a yearly cultivation and occasional deep soil tillage (after 3-4 years of interval), if required to break the plough sole are the most appropriate for irrigated soils under the small land holding farmers in the Sokoto State. Special efforts may be required to develop a suitable tillage system for fadama or valley bottom soils to reduce the cost and time of land preparation , and delay in crop planting.

INTRODUCTION:

A wide range of tillage practices (such as zero or no-till, minimum till (hand hoe, animal drown implements common under small irrigation projects in *fadama* ;low lying areas of river valleys), conventional and deep tillage), depending on the type of soil and crop grown, are used in Sokoto State. The conventional tillage in the large scale irrigation projects consists of ploughing to a depth of 20-25 cm followed by harrowing to the depth of 8-10 cm, generally after first rain, by the use of mechanical implements. Under irrigated agriculture, growing two or three successive crops on the same land in one year results in a more efficient utilization of irrigation water, climatic conditions, land, labour, machinery and other inputs. On the other hand and under intensive cultivation, the frequent use of machines (tractor traffic) or other animal drown implements of up to 7 times in a year for land preparation has the tendency to compact the soil and form plough sole which reduces the beneficial effects of tillage on the irrigated soil. The tillage practices in the *fadama* small scale (<2 ha) privately owned irrigation system (tubewell with 2" motorized water pump) are still primitive. The use of hand hoe, some animal drown implements are common. This warrants an urgent need for identifying the most appropriate tillage practices for various land holder farmers, soils and crops grown under irrigated farming.

MATERIALS AND METHODS

A survey of Sokoto State irrigation projects was conducted to study the existing tillage practices and related constraints. And later, a review of the previous findings and discussion on possible tillage systems with the Scientists of National Research Institute in region were conducted during the study.

RESULTS AND DISCUSSION

Farmer tillage practices under irrigated soil conditions
The large / medium scale irrigation projects (about 30,000 ha) are with the small land holder farmers (<50 ha). And small scale irrigation (about 20,000 ha) systems (privately owned) are mostly less than two hectare irrigated land in fadama areas. The irrigated land in the Sokoto State under various type of irrigation systems are less than 1.2 percent of arable land and 7.8 percent of the total potential irrigated land. The average annual rainfall varies from 550-750 mm. Most of the rain fall between mid June and mid September. Surface soil texture in these Fadama and other irrigation projects varied widely; ei, from sandy to heavy clay soil texture. The tillage practices also varies with the size of land holding and the system of irrigation as discussed below:

Small scale fadama irrigation project
Soils that occur in the low lying area of river valleys, lakes and other depressions are called Fadama soils. These soils are generally variable in texture and moist all the year round. Irrigated Fadama soils are normally cultivated through out the year using hand hoe or small animal-drawn implements. Minimum and zero tillage practices are common on these soils. The most common land preparation in irrigated fadama is by manual using hand hoes, spade and hand operated locally made plough. The small farm size (<0.2 ha) and location (hydromorphic), availability of family labour, and non availability of tractor and tillage implements restrict the use of mechanical land preparation in the fadama areas. In some areas, animal drown tillage implement are being used but not much common in the State. The fadama farmers having larger land holding (>2ha) do prefer the use of tractor at least once in a year for ploughing and harrowing but only a few lucky once gets from the Local Government or privately owned farmers. Presently the cost of land preparation by tractor is slightly cheaper than manual in irrigated fadama (Table 1). However, due to high labour demand in fadama crop cultivation and also manual land preparation, the planting of crops often gets delayed and yield gets reduced. The present World Bank funded two projects namely the National Fadama Development Project (NFDP) and the National Agricultural Technology Support Project (NATSP) under the Sokoto Agricultural Development Project are trying to introduce intermediate technology for land preparation such as animal drown implements and other possible alternative to ease the tillage operations under the small land holding in fadama irrigated system..

Table 1 Tillage practices on irrigated fadama soil[£] in Sokoto State.

Cropping Season	Land Preparation			
	Period	Tillage Practices*	No.of Ope. -ration	Cost& (N/ha)
Irrigated crops	Oct.-Dec.	-Manual;handhoes handplough,spade etc	25man/ha	1500
		-Tractor;plough-harrow	2 traffic	1250
		-Animal drown plough	2 traffic	NA
Supplemental irrigated crops	Feb.-Apr.	-Manual;hand hoes	20man/ha	1200
		-No-till using old beds	none	-
Rainfed crops	May-July	-Manual;handhoes spade etc.	25man/ha	1500
		-Tractor; harrow	1 traffic	500
		-Animal drown plough	2 traffic	NA

£ land holding<2 ha. * Most common order; US $ 1=22 & 45 Naira
& Labour charge-60 Naira/man/day; Tractor charge-750 and 500 Naira/traffic/ha for ploughing and harrowing, respectively.

Large scale irrigation project

A survey conducted on Bakolori (23,400 ha) Irrigation Projects (<10 ha land holding of farmer) reveals that tractor traffic (passes) for land preparation alone is up to seven times in a year on the same piece of land, depending on the intensity of cropping (Table 2). Cultivation on heavy clay soils presents a special problem. Plough is generally not used as it produces a cloddy seed bed. Though rotavator produces fine granular soil structure required for a good seed bed, it requires heavy tractors which may induce plough sole. Due to non- availability of heavy machines, farmers are now using disc harrowing from one to two times before planting of crop. Cost of mechanical land preparation varies with the crop and the availability of machines on hire. The mean cost of mechanical land preparations were 470, 322, 466, 325 and 270 Naira/ha for irrigated wheat, maize, tomatoes, onion and garlic, respectively. This accounts for about 15 per cent of total cost of production of cereal crops and about 7 per cent of total cost of production of vegetable crops (Maurya, 1993).

Effect of tillage practices on irrigated soil properties

Irrigated soils are normally subjected to intensive cultivation to derive the maximum benefits from the land. Due to the intensive cultivation, tillage pans could very easily develop on these soils. Kano River Irrigation Project is one such projects where tillage pans have developed in the Eutric Cambisols (Ahmed and Maurya, 1989). The top soil is usually loosened during conventional tillage but at some depth just below the plough layer, a compacted layer commonly called plough sole develops and is characterized by abnormally high bulk density. This layer restricts the water movement and

Table 2 Common tillage practices for land preparation under irrigated soil conditions in the large scale irrigation projects (Maurya, 1993).

Cropping& Season	Tillage Practices	Tractor Traffic	Cost* (N/ha)
a. Irrigated cropping (Wheat, Vegetable Maize, Rice)	**Choice I:****	4	420
	-Disc plough once to 20 cm		
	-Disc harrow twice to 10 cm		
	-Disc bunding & field layout		
	Choice II:	3	280
	-Disc harrow twice to 10 cm		
	-Disc bunding & field layout		
	Choice III:	1	110
	-Disc harrow once to 10 cm		
	-Manual bunding		
	Choice IV:	0	0
	-No-till		
	-Manual field lay out		
b. Supplemental irrigated crop (Vegetable Maize)	**Choice I:**	1	110
	-Disc harrow once to 10 cm		
	-Manual field lay out		
	Choice II:	0	0
	-No-till		
	-Manual field lay out		
c. Rainfed cropping (Rice, Maize, Cowpea, Vegetable, Sorghum, Millet)	**Choice I:**	3	280
	-Disc harrow twice to 10 cm		
	-Disc bunding & field lay out		
	Choice II:	1	110
	-Disc harrow once to 10 cm		
	-Manual field lay out		
	Choice III:	0	0
	-No-till		
	-Manual field lay out		

*Disc ploughing, harrowing and bunding cost 140, 110 and 60 Naira/ha (1US$=8 Naira).;&Irrigated cropping period: Irrigated crops-November to March; Supplemental crops-March to June; and Rainfed crops-June to October;**Not common on heavy clay soil.

gaseous exchange. Under such condition, deep tillage (sub-soiling, chiselling) has been reported beneficial for crop production, by improving soil physical and chemical properties. The increase in infiltration rate (Fig. 1) by about 3-8 fold and the bulk density in plough sole region was reduced to 1.61 and 1.58 g cm^{-3} by chiselling and sub-soiling, respectively, during the first year. The residual effects of deep tillage started declining from second cropping season. After three to four years of crop cultivation under normal conventional tillage, the beneficial effects of deep tillage diminished (Ahmed and Maurya, 1989). The changes in soil properties brought about by deep tillage are often transitory.

In the shallow or fadama soils deep tillage may result in mixing the surface fertile soil with the less fertile soil from below, producing little change in soil infiltration rate.

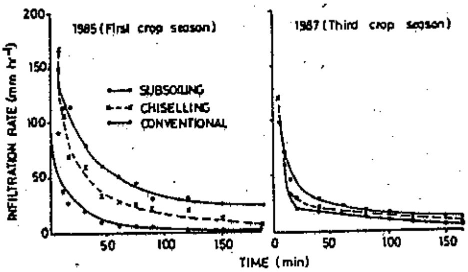

Figure 1 Effect of deep tillage on infiltration rate on the irrigated sandy loam soil (Ahmed and Maurya, 1989).

In semi-arid tropical condition of the Sokoto State, where it is normal to have only one rainfed crop per year, it is difficult to maintain the residue of the preceding crop because of termites and domestic cattles. Under such conditions, crops grown on untilled land are stunted and show symptoms of water and nutrient deficiencies because of high surface soil bulk density, low porosity, retarded infiltration and low water holding capacity of soil (Dunham, 1988 and Maurya, 1986).

In irrigated soil conditions, soils are generally moist, have higher air humidity and are cropped round the year. The continuous use of residue of the preceding crop as mulch on undisturbed soil maintained soil moisture and useful microflora activity. Under maize-wheat annual rotation on an irrigated sandy loam soil, no-tillage increased the soil porosity on surface soil horizon. However, no-tillage had adverse effect on the irrigated sandy soil in the dryer area of Semi-arid region and soil physical and chemical properties deteriorated over period of 3-4 years (Maurya, 1990). The minimum or no-tillage are the common tillage practice on the Fadama soil, which is normally moist all round the year and situated in high air humidity areas. Minimum tillage maintains the soil properties as well as the productivity of the fadama land.

Tillage and crop production on irrigated soil

Long term conventional tillage under intensive cropping and formation of plough sole make the plant growth and yield performance stabilized at the lowest level. Occasional deep tillage practice (sub-soiling or chiselling to a depth of 30-40 cm) accelerate the crop production for 1-2 year under the irrigated soil condition in semi-arid region (Ahmed and Maurya, 1989 and Miller, 1987). An experiment conducted to compare the various tillage practices on an Eutric Cambisols in northern Nigeria revelled that subsoiling and chiselling increased 10 and 20 percent the grain yield of wheat, respectively over conventional tillage during the first and the subsequent residual effect was not significant. The no-tillage practice is partially common in irrigated crop cultivation in Fadama and vegetable cultivation in the upland projects. Several long term experiments were conducted on irrigated sandy loam (slightly humid micro-climate) and sandy soil (Dry micro-climate) in the semi-arid region to compare the yield performance under no-tillage and conventional tillage systems. Maize-wheat annual crop rotation on irrigated sandy loam soil, the practice of no-tillage farming with the retention of adequate crop residue (5-6 t/ha) on the surface, maintained the total annual crop production, whereas on irrigated sandy soil having low fertility level, the annual crop production was always lower in the no-tillage than conventional tillage under large scale irrigation projects (Maurya, 1990).

SUMMARY:

Irrigated cropping systems have shorter period for the land preparation/ tillage operation. Normally farmer will try to avoid tillage operation for the rainfed or /and supplemental irrigated crops due to the lack of time and non-availability of tractor and timely labour. However, irrigated crops are being treated as the main crops of the project, therefore farmers prefer to prepare a good seedbed to have maximum benefit from irrigation. The combination of shallow and no-tillage in a yearly cultivation and occasional deep soil tillage (after 3-4 years of interval), if required to break the plough sole are the most appropriate for irrigated soils in the State.

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EFFECTS OF TILLAGE AND FERTILIZERS ON YIELD OF SORGHUM IN SEMI-ARID CENTRAL TANZANIA

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ABSTRACT

A researcher-managed experiment was conducted at Hombolo Research Station in Dodoma region of central Tanzania for two consecutive rainy seasons of 1991/92 and 1992/93 with the objective of investigating the effects of tillage and fertilizers on yield of sorghum *(Sorghum bicolor)*. The experiment consisted of seven tillage treatments combined with four fertilizer treatments on a complete randomized block design with three replications. The tillage treatments were zero tillage, flat cultivation, flat cultivation plus mulch, tied ridging, strip catchment tillage, tractor tillage and tractor tillage plus mulch. Fertilizer treatments consisted of no fertilizer (control), Farm Yard Manure (FYM) at 10 t ha^{-1}, Triple Super Phosphate (TSP) at 100 kg ha^{-1}, and FYM plus TSP at 5 t ha^{-1} and 50 kg ha^{-1}, respectively.

In two consecutive growing seasons, hand hoe cultivation increased the bulk density of the soil except on tractor tillage without-and-plus much where there was a decrease. Deep cultivation (by use of a tractor) increased the infiltration of water into soil mainly as a result of the reduction in bulk density. Crop performance, expressed as grain yield of sorghum, was better under deep tractor tillage than under shallow hand hoe cultivation. FYM gave remarkable grain yield increases compared to other fertilizer combinations.

INTRODUCTION

Nearly two thirds of Tanzania (with a total area of 939,701 km^2) can be described as semi-arid on the basis of having a probability of less than 25% of receiving 750 mm of rainfall per year. Dodoma Region, central Tanzania, is the driest area in Tanzania registering the lowest average annual rainfall (400-650 mm) and the longest dry season (8 months). Typical of low rainfall environments, the rainfall is unevenly distributed both spatially and temporally.

Agriculture is the basis of the population's mainly subsistence economy in Dodoma Region. Farming is entirely dependent on moisture supply from rainfall, and the frequent occurrence of mid-season drought is one of the main constraints to production. The possibilities of irrigating to supplement rainfall for crop production are limited for reasons of both expense and the lack of perennial sources of surface water and ground water. The key therefore to mitigating the effects of low and unreliable rainfall and stabilizing food production is more effective management of rain water. Management strategies include reduction of runoff losses, the concentration of rain water where appropriate through either off-or on-field water concentration practices and also improving efficiency of utilization of water by crops. Very little systematic research has been done in Tanzania on these aspects.

The objective of this report is to describe the effects of tillage and fertilizers on the yield of sorghum (*Sorghum bicolor*) in a semi-arid environment.

MATERIALS AND METHODS

A researcher-managed experiment was conducted at Hombolo Research Station in Dodoma region of central Tanzania for two consecutive rainy seasons of 1991/92 and 1992/93. The experiment consisted of seven tillage treatments combined with four fertilizer treatments on a complete randomized block design with three replications. The tillage treatments were zero tillage, flat cultivation, flat cultivation plus mulch, tied ridging, strip catchment tillage, tractor tillage and tractor tillage plus mulch. In the zero tillage plots, standing vegetation was manually slashed before making holes for planting using cutlasses down to 5 cm depth. Flat cultivation to 10 cm depth was performed using a hand hoe. Mulch (e.g. dead plant material) was added uniformly to the plots after planting. Tied ridging was done by first making parallel ridges along the contour at 0.75 m, and then the furrows were tied at 1.5 m intervals. Strip catchment tillage was performed by hand hoeing a strip of 10 cm wide on both sides of a crop row. Tractor tillage done using a disc plough down to a depth of 15 cm.

Fertilizer treatments consisted of no fertilizer (control), Farm Yard Manure (FYM) at 10 t ha^{-1}, Triple Super Phosphate (TSP) at 100 kg ha^{-1}, and FYM plus TSP at 5 t ha^{-1} and 50 kg ha^{-1}, respectively.

The test crop was sorghum (*Sorghum bicolor cv Tegemeo*) planted on 5 x 20 m plots laid out at 2% slope. Row spacing and within row spacing were 0.75 m and 0.30 m, respectively.

Soil bulk density and infiltration measurements were taken prior the initiation of the experiment and immediately after harvest in June according to Klute (1986). Grain yield was recorded at harvest.

RESULTS AND DISCUSSION

Soil physical properties

The soil bulk density for all hand hoe cultivated plots were higher than the pre-cultivation density even after two years since initiation of the experiment (Fig.1). Under tractor tillage treatments, there was a 0.7% decrease in bulk density for both tractor tillage and tractor tillage plus mulch at top (0-5 cm) soil depth.

At 10 -15 cm soil depth, however, the decrease in bulk density for both tractor tillage and tractor tillage plus mulch was 6%. The highest decrease in soil bulk density

(11%) was observed at 15 - 20 cm depth for tractor tillage plus mulch treatment.

During 1992/1993 cropping season, the 2-h cumulative infiltration values for both hand hoe cultivation and tractor tillage treatments are shown in Fig. 2. Compared to 1991/92 season, the cumulative infiltration increased by 28, 30 and 33% for flat cultivation, flat cultivation plus mulch, and tractor tillage plus mulch, respectively.

These results show that deep cultivation (using a tractor or otherwise) increases the infiltration of water into the soil mainly as a consequence of the reduction in bulk density of these naturally occurring hard-setting and crusting soils (MaCartney et al., 1971; Kayombo, 1993).

Crop response

Sorghum grain yield was significantly affected by both tillage treatments (Table 1) and tillage cum fertilizer treatments (Table 2).

In 1991/92 cropping season, hand-hoe cultivation treatments recorded higher grain yields than tractor tillage plots, with tied ridging registering over 2000 kg ha^{-1} (Table 1). Low yields in tractor tillage plots were attributed to late planting in these plots. Of tillage cum fertilizer treatments, Strip Catchment Tillage - FYM (1/2) + TSP (1/2) treatment gave the highest grain yield followed closely by Tied Ridging-Fertilizer combinations (Table 2). Positive grain yield responses of Strip Catchment Tillage-Fertilizer combination could be attributed to harvesting of water along the crop row from the uncultivated/trafficked interrow space (Willcocks, 1994). Although infiltration rate did not increase appreciably, tied ridges facilitated rainfall infiltration into the soil by retaining a major proportion of rainfall received on-site (Kayombo, 1992, 1993).

Table 1. Effect of tillage methods on grain yield of sorghum

Tillage method	1991/92	1992/93
	Yield (kg ha^{-1})	Yield (kg ha^{-1})
Zero tillage	1909 b	1462 b
Flat cultivation	1995 b	1689 b
Flat cultivation + mulch	1760 c	1252 b
Strip catchment tillage	1961 bc	1379 b
Tied ridging	2006 ab	1641 b
Tractor tillage	756 e	1693 b
Tractor tillage + mulch	1005 d	2143 a

Letters a-e denote significance at 5% level using Duncan's new multiple range test. Means with the same letter are not significantly.

In 1992/93 cropping season, the highest yields were obtained from tractor tillage both without-and-plus mulch (Table 1). When fertilizer was isolated as a factor influencing yield, FYM gave the highest sorghum grain yield compared to no fertilizer or FYM-TSP combinations (Fig. 3). Of the tillage cum fertilizer treatments, the tractor tillage plus mulch-FYM combination gave the highest significant grain yield followed by the tractor tillage plus mulch-FYM (1/2)+TSP (1/2) treatment (Table 2).

Table 2. Effect of tillage cum fertilizer treatments on sorghum grain yield

Tillage cum fertilizer treatment		1991/92	1992/93
Tillage	Fertilizer	yield (kg ha^{-1})	yield (kg ha^{-1})
Zero tillage	Control (No fertilizer	1952 abc	949 fg
	Farm Yard manure (FYM)	1862 abcd	1655 bcdefg
	Triple Superphosphate (TSP)	1954 abc	1739 bcdefg
	FYM ($^1/_2$) plus TSP ($^1/_2$)	1869 abcd	1849 bcdef
Flat cultivation	Control	1289 afgd	1405 cdefg
	FYM	2252 ab	2356 abc
	TSP	2044 abc	1164 defg
	FYM ($^1/_2$) plus TSP ($^1/_2$)	1995 abc	2246 abcd
Flat cultivation plus mulch	Control	1829 bcde	1427 cdefg
	FYM	1981 abc	1628 bcdefg
	TSP	1569 defg	891 fg
	FYM ($^1/_2$) plus TSP ($^1/_2$)	1863 abcd	1358 cdefg
Tied ridging	Control	2142 ab	2105 abcde
	FYM	2137 ab	2057 abcde
	TSP	2037 ab	1086 efg
	FYM ($^1/_2$) plus TSP ($^1/_2$)	2155 ab	1702 bcdefg
Strip catchment tillage	Control	1267 fg	665 g
	FYM	2152 ab	2102 abcde
	TSP	2037 abc	1407 cdefg
	FYM ($^1/_2$) plus TSP ($^1/_2$)	2386 a	1667 bcdefg
Tractor tillage	Control	493 hi	1116 efg
	FYM	903 ghi	2313 abc
	TSP	454 i	1487 bcdefg
	FYM ($^1/_2$) plus TSP ($^1/_2$)	1174 fg	2239 abcd
Tractor tillage plus mulch	Control	1002 gh	1795 bcdef
	FYM	918 ghi	2657 a
	TSP	828 ghi	1768 bcdef
	FYM ($^1/_2$) plus TSP($^1/_2$)	1273 fg	2555 ab

Letters a-i denote significance at 5% level using Duncan's new multiple range test. Means with the same letter are not significantly different.

These results show that crop performance was relatively better under deep tillage than under shallow cultivation. Furthermore, crop performance in this semi-arid environment was considerably improved by the application of FYM, although it is not yet known whether this effect is due to improved soil water retention or plant nutrients.

CONCLUSIONS

(1) In two consecutive growing seasons of 1991/92 and 1992/93, deep tillage reduced soil bulk density and increased infiltration of water into soil.

(2) Crop performance under deep tillage was better than under shallow cultivation.

(3) Farm yard manure (FYM) gave remarkable yield increases compared to other fertilizer combinations.

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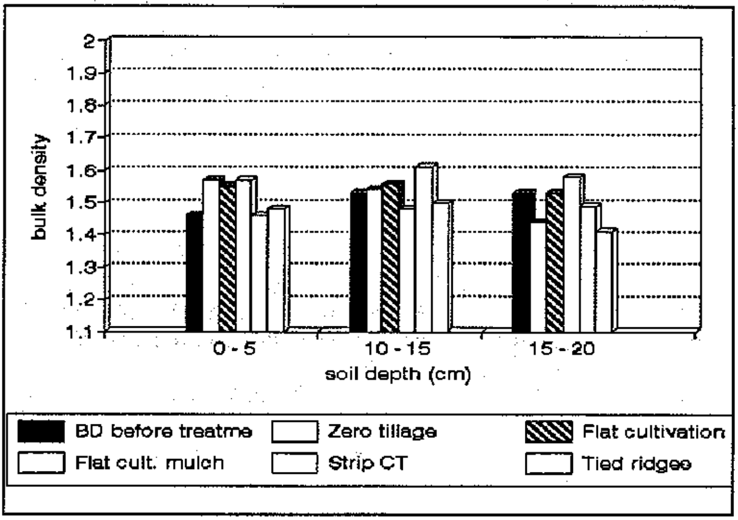
(a) Hand hoe cultivation



(b) Tractor tillage

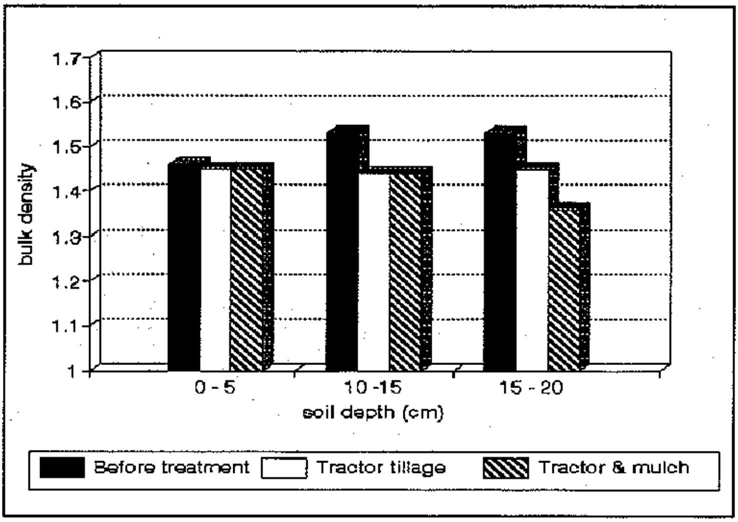
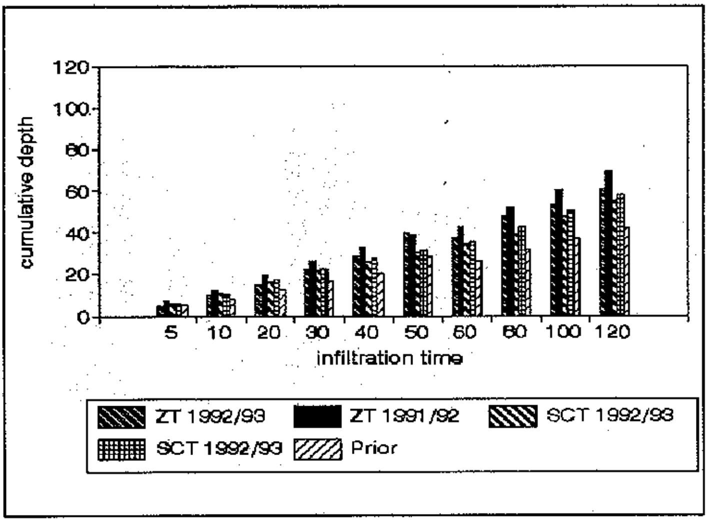


Figure 1: Bulk density under hand hoe and tractor tillage

(a) Zero tillage and strip cultivation



(b) Flat cultivation

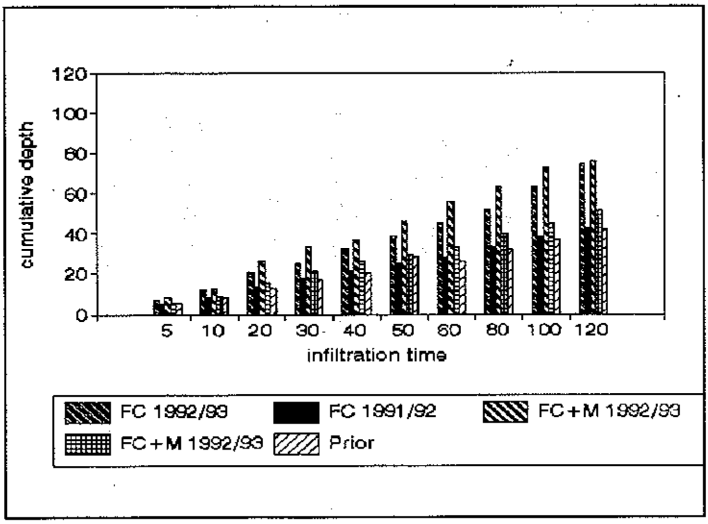


Figure 2:Cumulative infiltration before treatments for 1991/92 and 1992/93 seasons

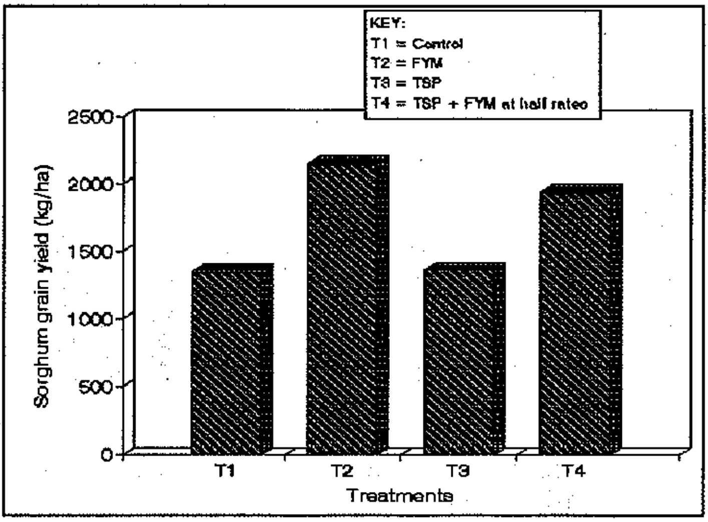


Figure 3: Effects of fertilizer on sorghum grain yield

SOIL TILLAGE AND ITS ROLE IN INCREASE OF SOIL FERTILITY AND STABILITY OF CROPPING CAPACITY

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ABSTRACT

Within the last 20 years, numerous stationary, field and greenhouse experiments were carried out in all native-economic zones of Russia and former union republics of the USSR for determination of the role of soil tillage in the increase of soil fertility and stability of the cropping capacity. The results of the scientific research were regularly generalized by the soil tillage Coordination Board headed by I.P. Makarov. Proceeding from the results of the investigations, the theory was refined and practical recommendations were given for differentiation of soil tillage systems based on the use of the generally accepted techniques relative to each particular soil-climatic zone and microzone, depending on the soil fertility, biological requirements of the plants being cultivated, and intensification of farming.

INTRODUCTION

Science as well as social economy have for a long time been interested in the problems of improvement of the soil tillage systems.

Firstly, our experiments prove that soil tillage is one of the most important factors regulating the humus balance of the soils, their agrotechnical and agrochemical properties and general fertility.

Secondly, soil tillage is the most energy-intensive technique. Presently, about 40% of the energy expenditures and 25% of the labour expenditures in cultivation of the agricultural crops fall on soil tillage.

Thirdly, in the course of tillage, the soil is adversely affected hy the running gears of the tractors, cultivators and tools which results in considerable deterioration of all properties of the soil. Our investigations show that apart from deterioration of the properties of top soil as well as subsoil, tillage promote erosion of the soil and decrease the cropping capacity.

Soil overcompaction is an important factor limiting the yield. It is worth while mentioning that in the last years the energy expenditures for soil tillage have grown up in our country hy 5.5 times, including the increase of the energy expenditures by 2 times at the expense of the non-recoverable resources. All this leads to the decrease of the efficiency of fertilizers, pollution of the soil, loss of land fertility, and decrease of the quantity and quality of the agricultural crop yields. The investigations produced a scientific base for improvement of soil tillage with respect to ecological and soil-protecting measures.

THEORETICAL BASIS OF INVESTIGATIONS

On the basis of numerous field and greenhouse experiments which were performed for estimation of the fertility of various top soil layers, it was established that differentiation in the fertility of the top soil layers was more pronounced on the sod-podzolic soils rather than on the chernozem soils.

The modelling experiments were made for studying the effect of the top soil turn-over, non-mouldboard loosening, and agitation of the top soil on the cropping capacity. This was done by determining the efficiency of each tillage technique as well as the effect of the thickness of the top soil. The experiments revealed the anti-erosive role of various soil tillage practices. They pointed out the reasons for soil compaction in cultivation of the agricultural crops, and for disintegration of the soil. Furthermore, it was detected how optimization of the crop rotation technologies on the basis of economic, ecological and technological standards of soil tillage could reduce soil compaction.

There was made allowance for the effect of tillage on the properties and fertility of the soil, and on growth, development and productivity of various plants in the crop rotation (the development of the root system and above-ground vegetative mass).

INVESTIGATION RESULTS AND THEIR DISCUSSION

(a) In the modelling greenhouse experiments, differences were found in soil fertility between soil layers. This differentiation was most pronounced on the sod-podzolic soils where the yield of the barley grains comprised from the upper layer (0 - 7 cm) - 100%, from the middle layer (7 - 14 cm) - 55.7%, and from the lower layer (14 - 21 cm) -

37.1%; on the chernozem soils, the total yield of the corn comprised: in the layer of 0 - 10 cm - 100%, in the layer of 10 - 20 cm - 88.2%, in the layer of 20 - 30 cm - 80%, in the layer of 30 - 40 cm - 45.9%, in the layer of 40 - 50 cm - 14.1%.

(b) the use of various soil tillage practices in the modelling greenhouse experiments proved their different effect on the yield of the agricultural crops:

- on the sod-podzolic soil, the yield of the harley grains in various layers of the top soil comprised:

  turn-over (14 - 21, 7 - 14, 0 - 7 cm) - 100%,
  non-mouldboard loosening (0 - 7, 7 - 14, 14 - 21 cm) - 138.9%,
  agitation (14 - 21, 7 - 14, 0 - 7 cm) - 129.1%

- on the chernozem, the total yield of the corn in various layers of the top soil comprised:

  non-mouldboard loosening (0 - 10, 10 - 20, 20 - 30 cm) - 100%,
  turn-over of the 20 cm layer (10 - 20, 0 - 10, 20 - 30 cm) - 84.3%
  turn-over of the 30 cm layer (20 - 30, 10 - 20, 0 - 10 cm) - 67.0%

(c) for selection of the technique and depth of tillage of the sod-podzolic soil, it was necessary to study the effect of arrangement of various fertility layers of 0-10 and 10-20 cm in the 20 cm soil. The modelling experiments revealed that the highest yields of the agricultural crops were obtained when the entire 20 cm top soil was made up of the soil with increased fertility, and the minimum yield was obtained when the top soil was composed of the soil sith diminished fertility. The mean yields were measured at various combination of the different-fertility layers of 0 - 10 and 10 - 20 cm in the 20 cm top soil.

(d) the modelling of the top soil from different-fertility layers proved that the yield of the agricultural crops depended not only on the fertility of the top soil but also on the fertility of the subsoil.

(e) in the result of estimation of the thickness of the top soil in the modelling experiments, it was established that the thickness of the top soil amounting to 40 cm, as compared with the top soil thickness of 20 cm, increased the efficiency of the fertilizers, provided more favourable living conditions for the plants, and ensured their high productivity.

(f) the study of the effect of soil compaction on the cropping capacity showed that utilization of more powerful wheel tractors increased the degree of soil compaction and reduced the yield, especially on the sod-podzolic soils. The use of the truck tractors leads to less compaction of the soil and less decrease of the yield, as compared with the wheel tractors. The efficiency of utilization of the combined implements was revealed.

The greenhouse and field experiments have made it possible to predict efficiency of the use of the differentiated tillage system in various soil-climatic zones of the country. As regards the sod-podzolic and grey forest soils of the Non-Chernozem Belt, the advantage is retained by the mouldboard treatments in combination with the non-mouldboard and surface treatments (placement of the fertilizers and stubbles, creation of the conditions in the soil for their mineralization).

On the chernozems and other soils of the steppe zone, the advantage is retained by the nonmouldboard treatment techniques (blade cultivator, chisel, soil slotter) in combination with periodic mouldboard treatment for elimination of differentiation in fertility of the top soil layers.

The main direction of improvement of the soil tillage systems in all soil-climatic zones consists in minimizing the soil treatment which guarantees preservation of the soils and stability of the cropping capacity.

MAIN CONCLUSIONS

1. For the increase of the soil fertility, use shall be made of the following rational soil treatment practices: the increase of the top soil, soil treatment without turn-over of the furrow slice, decrease of the quantity and depth of soil treatments, meliorative treatment of the soil.

2. Blade treatment of the soil decreases the rate of mineralization of the humus and diminishes inefficient expenditure of the soil nitrogen pool.

3. Long-term utilization of the non-mouldboard and surface treatments results in differentiation of the plough horizon in fertility, with a high content of the humus in the upper layer. In the lower layer, fertility becomes less than in the upper layer which adversely affects the fertility of the plough horizon as a whole.

4. At long-term utilization of the non-mouldboard and surface treatments of the soil, periodically (every 3 - 4 years) perform the mouldboard treatment with application of the organic and mineral fertilizers to eliminate differentiation of the top soil in fertility.

5. The study of the effect of the mouldboard treatment and several variants of the blade treatment of the soil on the calcareous, ordinary and leached chernozems in the grain-fallow crop rotation has shown that substitution of the blade treatment with the minimum quantity of deep treatments for the mouldboard treatment in the crop rotation

protects the soil from wind erosion and contributes to more economic expenditure of the organic substance.

6. On the peat-boggy soils, the intensity of decomposition of the organic substance in the top soil at surface treatment and without mechanical treatments is reduced, as compared with the mouldboard and non-mouldboard treatment practices, to a depth of 30 - 35 cm.

7. On the solonetz, the loss of the humus for 10 years of the grain-forage crop rotation at the mouldboard treatment of the soil has comprised 15% in the layer of 0 - 30 cm and 12% in the layer of 0 - 50 cm. At the non-mouldboard treatment of the soil, the loss of the humus has amounted only to 8 - 9%.

8. The blade treatment of the southern calcareous chernozems, as compared with ploughing, intensifies the rates of the microbiological and fermentative conversion of phosphorus into its available forms and generally favour the soil fertility.

9. The substitution of the blade soil treatment for the mouldboard soil treatment on the southern steppe chernozems has within 20 years increased the humus pool of the soil by 18 t/ha in the layer of 0 - 30 cm, has saved about 800 kg/ha of the total nitrogen, has increased the reserves of the movable forms of the nutrients, and has improved the physical properties of the soils.

10. Minimizing the treatment of the sod-podzolic soil promotes greater accumulation of phosphates and humus in the soil which adds to the soil fertility.

11. In the areas subjected to the water and wind erosion, it is important to make use of the practices reducing the effect of water and wind on the surface of the soil. Such practices include formation of a powerful vegetative cover in the period of vegetation and preservation of the crop residues on the surface of the soil, as well as formation of a mulching surface layer.

Thus, the main direction of improvement of the soil tillage system consists in minimizing soil treatment, differentiation of the soil treatment practices (alteration of the deep and shallow treatments, mouldboard and nonmouldboard treatments, surface and blade soil treatments), with due allowance for the soil and climatic conditions and for the requirements of the plants which are being cultivated.

MODELLING SUGARBEET SEEDLING EMERGENCE AND EARLY GROWTH

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ABSTRACT

A model designed to predict seedling emergence kinetics and seedling biomass distribution for sugartbeet is described. The input variables are the soil and climatic conditions (rainfall, air temperature, incoming radiation, soil surface texture), characteristics of the seed material (initial seed weight distribution, germination kinetics, hypocotyl elongation), and environmental conditions created by seedbed preparation and drilling (aggregate size distribution in the seedbed and on soil surface, sowing depth distribution). This model estimates soil temperature and superficial crust development at daily intervals. The germination times are calculated with reference to changes in soil temperature. The time needed to reach the soil surface is then calculated using germination time, soil temperature, the presence or absence of aggregates, and the hypocotyl elongation function. The seedlings ability to break through the soil surface is estimated as a function of crust development and moisture. The seedling growth after emergence is calculated with reference to seed weight distribution, emergence delay and the presence or absence of a mechanical obstacles. This model helps to identify the seed and seedbed characteristics that have the greatest influence on field emergence.

INTRODUCTION

There is a great need to be able to predict the effects of technical changes on crop establishment. Soil tillage, seedbed preparation and sowing techniques are rapidly changing and represent heavy costs for growers. But the effects of these changes are not easy to predict : they induce changes in the seedbed characteristics and in the seed placement which interact to determine the crop stand. Their effects also depend greatly on the climatic sequences that follow seed sowing. Conventional experiments comparing the plant population and the final yield for different management techniques are time and money consuming. Their results depend on the experimental soil and climatic conditions. A simulation tool, that could predict seedling emergence and early growth would be useful for experimenters. It could be used to estimate the major effects of different changes in the seedbed layer or in the seed characteristics, under different simulated climatic scenarios. This paper presents the framework of a model simulating the emergence and early growth of sugar beet. This type of approach has been developed on other plants (1 on wheat), but only descriptive studies on the variations in crop establishment were reported for sugarbeet (2, 3). The model described here is designed to take into account four main sources of variability in the crop establishment : (i) the variability within the seed population, (ii) the climatic variations in time and between sites, (iii) the seed placement variations, (iiii) the differences in soil structure resulting from tillage operations. It not only predicts the emergence rate, but also the early growth of the seedlings. These output variables could be used to initialize crop growth models, in which the crop establishment variability is often poorly taken into account.

PROCESS CHART OF THE SIMULATION MODEL

Basic principles

The simulation process is outlined in figure 1. The output variables are the germination and emergence kinetics, the emergence rate, and the seedling growth parameters until the first pair of leaves appear. The input variables are the seedlot characteristics (seed weight distribution, germination kinetics, parameters of the hypocotyl elongation function), soil and climatic characteristics and other conditions resulting from the tillage and sowing operations (aggregate size distribution, sowing depth distribution). Dynamic submodels are used to simulate the processes at daily intervals : (i) physical models characterising the seedbed layer conditions and their evolution with time (temperature, soil surface state), (ii) biological submodels working on an individual basis (seed by seed). The seed characteristics are sampled N times, in distribution tables characterising the seed population for different variables : the seed weight, the germination time, the function describing the hypocotyl elongation, the seed position in the seedbed layer. Then, the biological submodels are reiterated N times to generate the distribution of the predicted variables.

Sub-model characteristics

Soil temperature prediction
The daily mean seedbed temperature is predicted using a semi-empirical relationship between air and seedbed temperatures (4). The following equation is used :

$$Tsb = Tair + (\alpha + \beta\,(1\text{-}a)\,Sr)$$

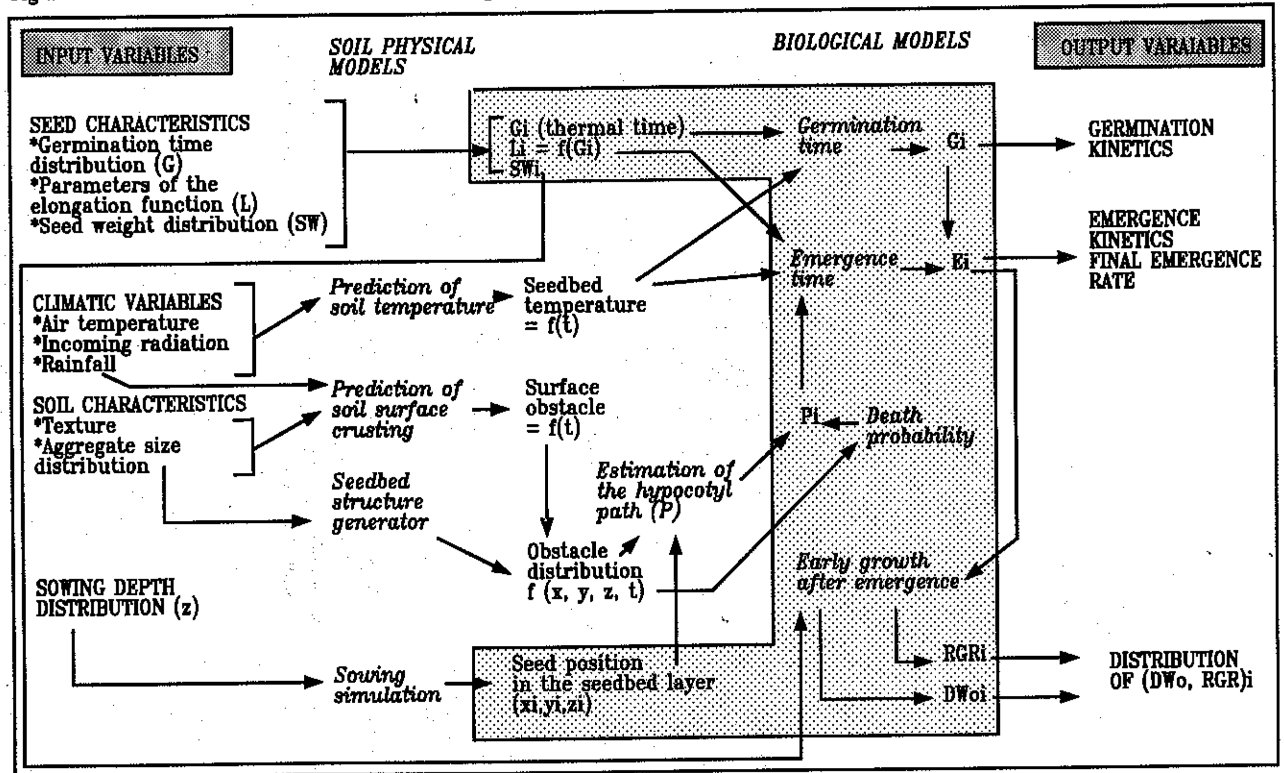
with Tsb= seedbed temperature
Tair = air temperature
a = soil albedo
Sr = solar radiation (Wm^{-2})

α and β values (respectively 0.2 and 0.01) were estimated from experiments where seedbed temperatures were measured in three different soil types, with albedo varying from 0.15 to 0.30.

Soil surface crusting
This submodel generates a qualitative variable describing the surface state, assumed to be continuous. This variable has only two modalities : obstacle to emergence or not. The choice between the two modalities is determined by taking into account the cumulated rainfall and the maximum daily rainfall from the sowing date up to the current day (5). These climatic variables are compared to threshold values depending on soil texture to determine if a crust is present or not. If there is one, the crust is considered as an obstacle if there have been at least j days without rainfall between crust formation and the considered day (j may be indexed on evaporation and soil texture). A future improvement in this submodel will be to introduce a spatially distributed network of cracks instead of considering the crust as continuous.

Seedbed structure generator and sowing simulation
The seedbed layer is characterised by the number of clods of a given diameter in a definite volume above the seed (Y = sowing line width, X = 10 cm length on the sowing line, Z = mean sowing depth). The clods are assumed to be spheric. The position (x,y,z) of the clod center is choosen at random in the definite volume. This position is accepted only if the clod periphery does not overlap the periphery of the other clods, already placed in that volume. The seed (i) is placed in that seedbed by choosing a sowing depth at random in the sowing

Figure 1 Process chart for simulation of the sugar beet emergence



Italic characters = models Roman characters = variables N iterations depth distribution (zi), by choosing at random the y abscissa (yi), and by choosing the x abscissa (xi) in a Gaussian distribution.

Predicting germination time

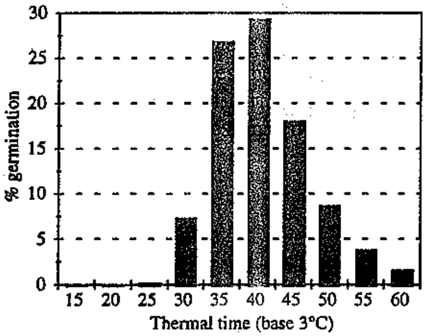


Figure 2 Germination times distribution (established on a Vega seedlot ; T = 10, 15, 20°C ; n=300 at each temperature)

In the present state, imbibition is assumed not to be limited by moisture conditions, so that germination is not influenced by the seedbed water content. This assumption corresponds to the most frequent conditions in the sugar beet cropping area of Northern Europe (2, 5). Thermal time (using a 3°C threshold value) is cumulated from the sowing date. This heat sum is compared with the thermal time requires for germination of the seed (i), which is choosen at random in the distribution of germination times of the seedlot. If the cumulated thermal time from sowing is equal to the time required for germination of the seed, then the seed is declared germinated. An example of this distribution is given in figure 2. An infinite time is given to seeds which cannot germinate.

Estimating the hypocotyl path and length

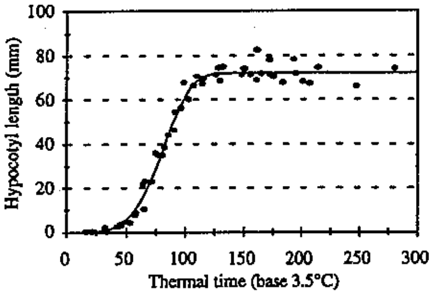
This submodel calculates the hypocotyl course on the basis of the following hypothesis :

- clods are assumed to be spherical, impenetrable, and immovable if their diameter is > 2mm,
- the hypocotyl follows a vertical course if it does not meet aggregates with a diameter >2mm,
- if the hypocotyl runs into an aggregate of diameter > 2mm, then :
    . (i) either it goes on elongating and grows around the clod, following an arc of a circle in close contact with the sphere. The arc length is calculated with reference to the point where the seedling touched the sphere, and the angle that the seedling needs to go around the sphere. This angle is choosen at random, with respect to the positive geotropism of the hypocotyl.
    . (ii) or it stays under the clod and the seedling die.

The choice between (i) and (ii) is determined by random drawing in a probability table depending on the clod diameter. A aggregate diameter increase from 5 to 30 mm increases the seedling death probability from 0 to 0.65.

Predicting emergence time

This submodel determines the time (thermal time from sowing and Julian day) at which the seedling reaches the soil surface with reference to the thermal time (base 3.5°C) cumulated from germination, the estimated hypocotyl length, and the hypocotyl elongation rate.The parameters of the elongation function (example in figure 3) depend on the germination time (Gi).



$$L = A(1 - e^{(-Bt)^C})$$

with $A = 72.0895$

$B = 0.0115$

$C = 4.5701$

Figure 3 Hypocotyl elongation function (established on a Vega seedlot, T=10, 15, 20, 25°C, n=15 seedlings for each point)

When this time is calculated, two successive tests are done :

- if the age of the seedling, expressed as thermal time from sowing, is above 175 degree-days (base 3.5°C), the seedling is considered as dead,
- if not,
  . if there is no crust, or a wet crust, the seedling emerges. Its emergence time (Ei) is equal to the time calculated to reach the soil surface ;
  . if there is a dry crust, then, as long as the seedling age is below the threshold value determining the seedling death, thermal time is cumulated until the crust is rewetted. The seedling then emerges. Its emergence time is equal to the cumulated thermal time needed to reach the soil surface and to wait for favourable crust moisture. If the crust is not rewetted before the thermal time for death is reached, the seedling fails to emerge and is considered as dead.

Predicting early growth

This submodel is based on the hypothesis of exponential growth, with two parameters to estimate : the intercept DWoi and the slope RGRi. Dwoi depends on the initial seed weight (6). A linear relationship was found in experiments related in (6), carried out on a given seedlot (Cv Vega) :

$$DWoi = 0.0045 + 0.740\ SDWi$$

with SDWi = seed (i) dry weight (without its teguments).

($r = 0.82$; $n = 167$)

RGRi depends on the emergence time, ie the duration of the seedling growth under the soil surface. If the emergence time is less than 100 degree-days (base 3.5), then the RGR is not modified (7). If it is more than 100 degree-days, or if the hypocotyl had met an obastacle before emergence, it decreases (7, 8).

CONCLUSION

Experimental work is still being conducted to acquire the parameters of the biological

submodels. The experiments cover : (i) the influence of the germination time on the hypocotyl elongation function, (ii) the relationship between clod diameter and emergence probability, (iii) the changes in RGR when the hypocotyl meets an obstacle before emergence, (iiii) the improvement of the index of emergence disturbance when the seedlings meet a crust. The validation of the model for situations with no obstacle in the hypocotyl path will show wether the biological variabilities in seed and seedling behaviour are correctly described by the biological models and their parameters.
Further planned improvements include : (i) incorporation of a submodel predicting germination in dry conditions, (ii) more accurate prediction of the dynamic of crust formation, especially the changes in crust dessication. These two improvements require a physical submodel predicting the changes in soil water content at hourly intervals and depth steps of few millimeters. This means more determinist models.

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MODELLING LONG TERM EFFECTS OF CROPPING SYSTEMS ON SOIL STRUCTURE

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ABSTRACT

In order to study long term effects of cropping systems on soil structure, we propose a compaction index. It is based on the evaluation of the compacted volumes in some precisely defined zones of the Ap layer, delimited by the geometry of the wheel tracks. This index has been evaluated in three experimental plots, in which controlled traffic insured a precise localisation of these zones. The different cropping systems investigated lead to specific values of the index. A simulation of the evolution of the index is proposed, based on a compartmental model, in which the dynamic of soil structure is related to soil management. The results of the simulation lead to the assumption of an evolution of the index towards an equilibrium value, characteristic of the cropping system.

INTRODUCTION

Processes affecting soil structure evolution of the top soil layer (Ap layer) are complex, involving the nature and date of the cultivation operations, climate effects and biological actions. These actions affect soil porosity at different scales (in a positive - fragmentation - or negative - compaction - way). In some cases, (moulboard ploughing for instance) tillage also displaces soil volumes. Soil structure is then, at a given time, the result of an history, characterized by a given sequence of external forces, having contradictory effect on the porosity, the size of soil particles and their localisation in the profile.
It is very difficult to study such sequences, especially over several years, in the field. Therefore, in addition to field studies, there is a great need for models, using characteristics of soil, climate and cropping systems as input data in order to predict soil structure evolution.

In order to contibute to such a modelling, we propose in this paper (i) a compaction index, able to reveal the history mentioned above, which has been evaluated in 3 experimental plots, and (ii) a simulation model of this index evolution.

MATERIALS AND METHODS

Description of the experimental plots

The index has been measured in 3 experimental plots for which the geometric pattern was well known, over a ten years period. The experimental plots are localised in the West part of the french Bassin Parisien, at Grignon (Yvelines). The soil is an hapludalf (soil taxonomy). Essential soil data are shown in Table 1. In these situations, for each operation, except ploughing and harvest, the working width is the same (1,75 meter), so the wheels tracks are perfectly localized. They are also at the same place every year. Conversely, wheeling during harvest is not controlled. The plots are ploughed every year, with a two bodies mouldboard plough. Each body has a cutting width of 0.35 meter. Ploughing depth is 0.25 m.

Table 1 : Mean soil characteristics of the four experimental plots (% w/w)

Particle size distribution			Organic matter	$CaCO_3$
< 2	2-50	50-2000 mm		
23.5	66.0	10.5	1.4	0.9

For each crop (table 2), cultivation consists of a ploughing usually made during november, a shallow cultivation (using a rotary cultivator) made just after ploughing for wheat, rape or alfalfa and in spring for maize. Drilling is performed at the usual dates for this area, with a 1.75 m width seed drill. All the further operations (fertilizer and pesticide spraying) are made using the same wheel tracks, except the harvest, performed with a three meters width combine harvester for wheat, alfalfa and rape, and a two lines corn picker for maize.

Table 2 : Successive crops on the three experimental plots. 1

	Harvesting date									
Plot	76	77	78	79	80	81	82	83	84	85
1	B	B	B	L	L	L	L	B	C	B
2	B	B	M	B	B	C	B	C	B	B
3	M	B	M	B	M	B	M	B	M	B

B : Winter wheat ; L = Alfalfa ; C = Rape ; M = Maize

Definition of a compaction index, related to the history of the cropping system.

For a given crop, intensity of compaction depends on the proportion of the field surface wheeled and the water status of the soil when the operations occur. So, for each crop, one can reconstruct a specific "traffic pattern" (1), based on the analysis of the equipment geometry (working width, tyres characteristics,...) and the localisation of the successive tracks for each operation. It is then possible to distinguish, in the field, wheeled areas from those which didn't have been compacted. As mouldboard ploughing displaces soil volumes, this identification has only sense for operations made after ploughing. In the no-wheeled areas, any compacted clod is then inherited from pre-ploughing operations, and can be considered as a "memory" of ancient compaction.

On the other hand, fragmentation actions due to tillage are localized all over the field surface, but at different depths. The deeper effect is usually obtained with the plough ; harrowing only affects the first top centimeters of the Ap layer. It is then possible to distinguish within the Ap layer, soil volumes related to the nature of the mechanical constraints (the mechanical history) they have been submitted to, as shown in Fig. 1.

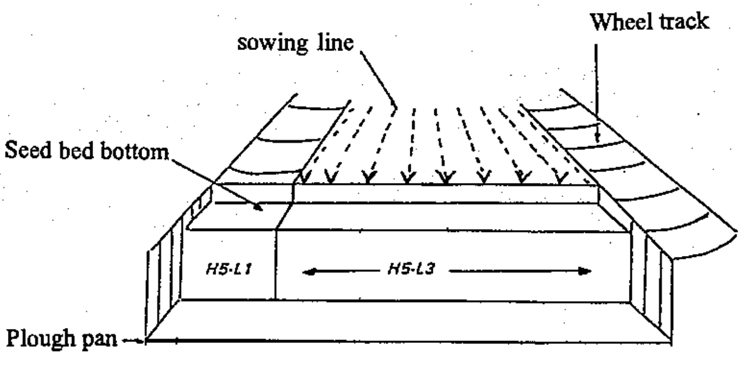


Fig. 1 : Principle for the partition of soil profile in experimental plots

One can see from Fig. 1, that the part of the profile which is the best fitted to our objective to measure cumulative effects of the cropping system, is the part called "H5-L3". *The index is then defined as the proportion of compacted elements localized in the part of the profile free from post-ploughing actions of compaction and fragmentation* (2).

Field evaluation of the index

The principle of the evaluation is based on the fact that, for a given texture at a given humidity, compacted clods have a greater bulk density than non-compacted ones (3). Soil samples have been removed from the H5-L3 part of the profile. Samples were air dried. Fine earth (agregates les than 2 centimeters) and clods were separated. Each clod was included in paraffin, then put in a liquid ($ZnCl_2$ solution) whose density allowed a separation of the two populations of clods. The index was then defined as :

$$I = \frac{\text{weight of the compacted fraction}}{\begin{array}{c}\text{total weight of the sample}\\ \text{(non compacted clods and fine earth)}\end{array}}$$

Four profiles have been described in each plot. In each profile, six samples were taken from the H5-L3 part. The index evaluation was performed in april 1985.

RESULTS AND DISCUSSION

Results and interpretation

Results of the index evaluation are shown in Table 3. Two kinds of cropping systems are separated by the mean value of the compaction index : cropping systems 1 and 2, in which there are only winter crops (except one maize the third year in plot 2), and cropping system 3, including one maize every two years. This suggests that maize crop is responsible for the high level of the index. Assumption is made that it is compaction during the only operation whose tracks are not controlled (harvest) which is reponsible for the high level of the index.

Table 3 : Evaluation of the compaction index

Plot	Index (%)	Confidence interval (5%) Min value	Max value
1	32.6	23.4	41.8
2	34.7	24.3	44.5
3	68.3	60.7	76.3

As wheels tracks positions are strictly controlled in this experiment, there are two hypothesis to explain the presence of compacted clods in the H5-L3 (no wheeled) parts of the profiles in plots 1 and 2 : (i) compaction during harvest, which is most improbable because in these plots this operation takes place in summer, when the soil is dry ; and (ii) apparition of compacted clods due to lateral displacement of the compacted zones, during ploughing. The higher level observed in plot 3 would then be due to the same lateral displacement **and** the compaction during harvest, in autumn, every two years.
The model we propose is based on these assumptions. The principle is presented on fig. 2, in the case of plot 1 (i.e. without compaction outside compartment 1, during harvest).

Description of the model

We propose a compartmental model, with five compartments, the first one corresponding to the soil volume localised under the wheel track, and each of the four others to the volume of soil cut by a plough body (Fig. 3). This volume will be called the *furrow slice*. Each

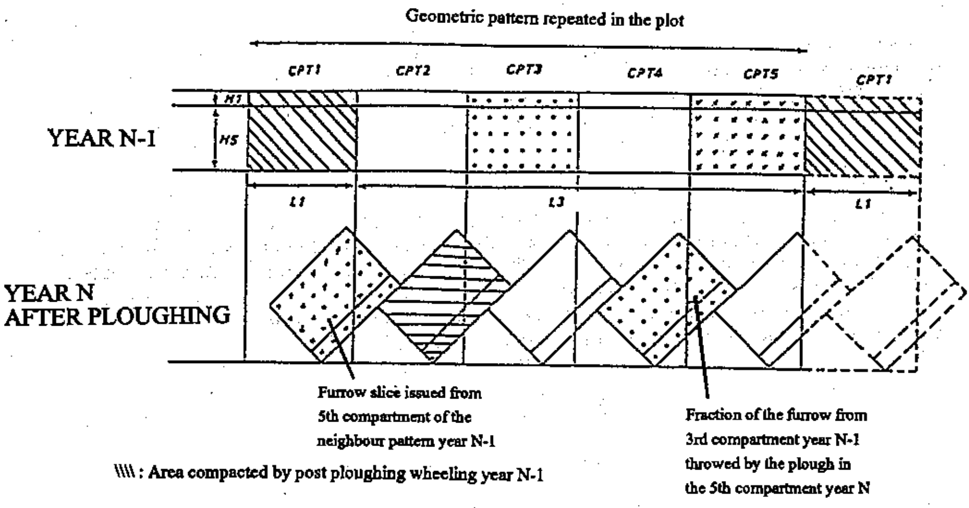
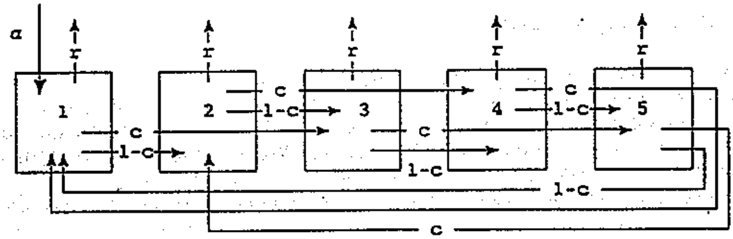
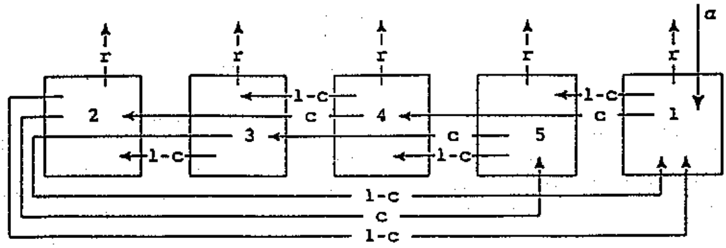


Fig. 2 : Principle of the dynamic of soil structure in plot 1. Ploughing effect



IF DISPLACEMENT OCCURS TOWARDS THE RIGHT ...



... IT IS TOWARDS THE LEFT THE NEXT YEAR

Fig 3 : Diagram of the compartmental model

Each compartment is characterized by its compaction index (x_i)

compartment is characterised by its proper compaction index (x_i) ; the output data (I) is then the mean of the four values x_2 to x_5.
The evolution of the index in each compartment is determined by soil tillage :

. *Compaction* occurs, for a given year, in the first compartment, whatever the climate, because the high number of passes (at least six) during the cultivation season. Each year, the compaction index of the first compartment is then fixed to a given value, **a.**

. During ploughing, *lateral transfer* induce mixing between compartments, and that is modelised with a transfer coefficent **c.** Displacement year n is opposite from displacement year n-1, because the moulboard is throwing the earth alternatively towards the right and towards the left from one year to another. There is a loop, because the pattern is repeated in the field, so transfer occurs from one pattern to the next one.

. *Fragmentation action,* due to shallow cultivation, induces a decrease of the proportion of compacted clods. We assume that, during shallow cultivation, the clod size is reduced to a value smaller than 2 centimeters (clods are changed in fine earth). The proportion of compacted clods disapearing each year is the parameter **r.**

The state equation of the model can be written (for a displacement towards the right, in a matrix form : $X_t = M * X_{t-1} + U_t$,

$$\begin{array}{ccccccc} X_t & & M & & X_{t-1} & & U_t \\ \begin{vmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \end{vmatrix} & = (1-r)* & \begin{vmatrix} 0 & 0 & 0 & 0 & 0 \\ 1-c & 0 & 0 & 0 & c \\ c & 1-c & 0 & 0 & 0 \\ 0 & c & 1-c & 0 & 0 \\ 0 & 0 & c & 1-c & 0 \end{vmatrix} & * & \begin{vmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \end{vmatrix} & + & \begin{vmatrix} a \\ 0 \\ 0 \\ 0 \\ 0 \end{vmatrix} \end{array}$$

Results of the simulation

The values chosen for the parameters are :
c = 0.24 : 24 percent of the total furrow slice from the ith compartment is in the (i+2)th compartment after ploughing. This value has been evaluated by geometric analysis of the ploughing model presented on Fig. 2 (4). We assume that the compacted clods are homogeneously distributed in the furrow slice.
r = 0.20. This value has been calculated assuming that the disparition rate was proportional to the fraction of total Ap affected by the rotary harrow : the working depth is 0.05 m, 20% of the total depth of Ap (0.25 m).
a = 1.0, which means that every year, the compartment 1 is entirely compacted.
The same values are used for the 3 simulations. Initial state of the system was chosen with no compacted clods in the compartments ($I_0 = 0$). For the simulation of plots 2 and 3 we have chosen to force one randomly chosen compartment of H5-L3, every year with a maize crop, to simulate the compaction effect of the harvest.

Results are shown on Fig. 4, for plots 1 and 2, and Fig. 5 for plot 3. From Fig. 4, it appears that the index reaches an equilibrium value, after some iterations of the model. In the case of plot 2, the presence of maize the third year induces a sudden increase of the index value, which returns towards the equilibrium value of plot 1, after some time : the equilibrium is stable. With the set of parameters chosen, the equilibrium values obtained are very close from those observed in experimental plot. From fig 5, it appears that there is also an equilibrium value, but the system is fluctuating, after some iterations, around this value. This value (obtained with the same set of parameters than for plots 1 and 2) is close to the one observed in the third experimental plot.

CONCLUSION

With the set of parameters chosen, the equilibrium values obtained by simulation are close to the index values measured in experimental plots.

This suggests that the assumptions made about cropping system effects on soil structure are plausible. This model should allow analysis of long term effects of cropping systems more complex than the ones studied in this experiment.

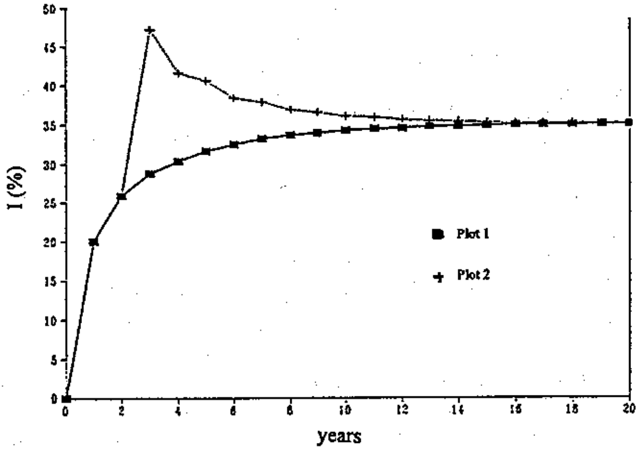


Fig. 4 : Results of the simulation for plots 1 and 2.

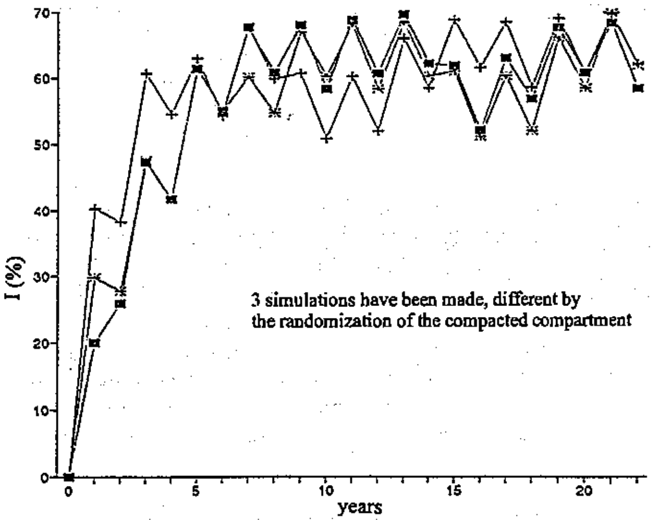


Fig 5. : Result of the simulation for plot 3.

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QUANTIFYING THE RATE OF CHANGE IN SOIL STRUCTURE SUBSEQUENT TO THE INTRODUCTION OF FORAGES

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ABSTRACT

A semi-empirical model has been developed to compute the change with time in the structural characteristics of soils after the introduction of new cropping practices. The change was described as a function of the maximum change possible and a rate constant, using a first order exponential equation. The rate of change in the stabilization of structural units $<2\ \mu$ was described after the introduction of forages for different soils. The equation accounted for 50 to 80% of the temporal variation in the stability characteristics. Pedotransfer functions were developed to allow comparison between soils using soil inventory information. The stability increased at a faster rate on soils with higher clay and organic matter contents and soil pH. The semi-empirical model appears to be applicable to other soil structural characteristics and may, therefore, be particularly useful for characterizing changes in a range of soil physical properties that are caused by the introduction of new cropping practices.

INTRODUCTION

The structural stability of soil has an impact on a wide range of processes that influence crop growth, erosion, runoff, and the transport of contaminants from farm land to streams and surface water bodies. Structural stability can be considered at scales ranging from that of clay-sized particles (μ) to that of macropores and peds (cm). Stability can vary with changes in cropping systems and/or tillage practices, environmental factors and characteristics of the pore fluid. Limited information exists, however, on procedures that will facilitate computation of changes in stability with time subsequent to the introduction of specific cropping or tillage systems when there are fluctuations in environmental factors. Such computational procedures must be capable of dealing with temporal variations in stability within a growing season that are caused by changes in management practices when these changes may be smaller than changes in stability due to climatic factors.

The objectives of this study were to: (i) develop a semi-empirical model to predict changes in stability subsequent to the introduction of forages, (ii) assess the model using data from different soils, and (iii) to determine the influence of soil properties on stabilization.

THEORY

The model is developed to describe stability at the level of clay sized particles. The dispersibility of clay from moist soil aggregates has been shown to increase linearly with water content at the time of sampling, i.e.

$$DC(\theta) = p + q\,\theta \qquad [1]$$

where DC is the amount of clay that is dispersed and expressed as a percentage of the total weight of soil, θ is the gravimetric water content (%) and p and q are parameters to be determined by regression analysis. Equation [1] can be rewritten in terms of stabilized clay, SC, as follows:

$$SC(\Theta) = TC - (p + q\,\Theta) = v - q\,\Theta \qquad [2]$$

where TC is the total clay(%) and TC - p = v. If introduction of forages onto a soil that has been used for the production of corn for an extended period changes the SC(Θ) function, then the value of SC at any time, t, subsequent to the introduction of forages can be defined as:

$$SC_f(\Theta_f,t) = v_f(t) - q_f(t)\,\Theta_f \qquad [3]$$

where the subscript f refers to the forage treatment. The SC for corn, the control, will not vary with time if the soil has been used for the production of corn for an extended period of time and therefore,

$$SC_c(\Theta_c) = v_c - q_c\,\Theta_c \qquad [4]$$

where the subscript c refers to the corn treatment. The Θ at sampling is also subscripted because it could vary with cropping treatment.

When forages are introduced, SC would increase and reach a maximum value, $SC_f(\Theta_f)_{max}$, as $t \rightarrow \infty$, where

$$SC_f(\Theta_f)_{max} = v_{f\,max} - q_{f\,max}\,\Theta_f \qquad [5]$$

The minimum value of $SC_f(\Theta_f)$ corresponds to,

$$SC_f(\Theta_f)_{min} = v_c - q_c\,\Theta_f \qquad [6]$$

The difference between the maximum and minimum values of SC_f gives the maximum potential change in SC, i.e., $\Delta SC_f(\Theta_f)$, and is given by

$$\Delta SC_f(\Theta_f) = SC_f(\Theta_f)_{max} - SC_f(\Theta_f)_{min} = \Delta v - \Delta q\,\Theta_f \qquad [7]$$

where,

$$\Delta v = v_{f\,max} - v_c \quad [8]$$

and, $\Delta q = q_{f\,max} - q_c$. [9]

The value of $SC_f(\Theta_f,t)$ is then defined as:

$$SC_f(\Theta_f,t) = SC_{f\,min}(\Theta_f) + \Delta\, SC_f(\Theta_f)\,.\, f(t) \quad [10]$$

$SC_f(\Theta_f,t)$ is expected to increase with time. This requires that f(t) increases with time from zero at $t = 0$ to one as $t \rightarrow \propto$. In addition, the function would be expected to increase slowly from zero initially, increase more rapidly and then exponentially approach one. The following function approximates these requirements:

$$f(t) = 1\text{-}e^{-k(t-tl)} \quad [11]$$

where k is the rate constant and t_l is the lag time such that

$$SC_f(\Theta_f,\ t < t_l) = SC_{f\,min}(\Theta_f) \quad [12]$$

Now Eq.[10] is modified to include Eqs.[11] and [12],

$$SC_f(\Theta_f,t>t_l) = v_c - q_c\Theta_f + (\Delta v - \Delta q\ \Theta_f)(1\text{-}e^{-k(t-tl)}) \quad [13]$$

If the impact of wetting and drying cycles, age hardening (gain in stability or strength over time in the absence of external stress), as well as freezing and thawing events on SC are not influenced by management practices, the impact of these processes can be minimized by considering the corn treatment as the control and always subtracting the value of SC for corn from the corresponding value for the forage treatment to produce the net stabilized clay, SC_{net}, ie:

$$SC_f(\Theta_f,t>t_l) - SC_c(\Theta_c) = v_c - q_c\Theta_f + [(\Delta v - \Delta q\ \Theta_f)(1\text{-}e^{-k(t-tl)}) \\ - (v_c - q_c\ \Theta_c)]$$

$$SC_{net} = (\Delta v - \Delta q\ \Theta_f)(1\text{-}e^{-k(t-tl)}) + q_c(\Theta_c - \Theta_f) \quad [14]$$

The ability of forage treatments to stabilize clay can be characterized by the maximum potential increase in stabilized clay, $\Delta SC_f(\Theta_f)$, and the rate at which the increase in stabilization occurs. The $\Delta SC(\Theta)$ in a given soil at the average water content, $\bar{\Theta}$, is given by

$$\Delta SC_f(\bar{\Theta})_f = (\Delta v - \Delta q\ \bar{\Theta}_f). \quad [15]$$

The time required for the forage treatment to increase SC_{net} of a soil to a point midway between the initial minimum to the maximum value is a meaningful variable for advisory purposes to describe the rate of change in clay stabilization when a new soil or crop management practice is introduced. Perfect et al. (1990) defined this variable as half-life, $t_{1/2}$. Mathematical manipulation of Eq.[14], at constant Θ would produces the following equation,

$$t_{1/2\ (SC_{net})} = t_i - \ln(0.5)/k. \qquad [16]$$

The ratio $\Delta SC_f(\bar{\Theta}_f)/DC_c(\bar{\Theta})$ describes the fraction of the clay that was initially dispersible that can potentially be stabilized by forages.

MATERIALS AND METHODS

Field experiments

Soil samples were collected in 1989, 1990 and 1991 from seven sites of different texture (Table 1) and on which crop-rotation-soil structure studies had been initiated by different investigators in 1989. The cropping treatments at the sites included conventionally tilled continuous corn and corn-forage rotations. Throughout the sampling period the corn-forage rotation plots were in the forage phase. The experimental design at each site was a randomized complete block with four replications. The mineralogy of the soils was dominated by illite with lesser amounts of chlorite, vermiculite and hydroxy interlayered vermiculite.

Table 1. Description and selected properties of the soils.

Soil	Series name (US Classification)	Clay (......	Silt ......%......	OM* ......)	pH	$CaCO_3$ (%)
1	Brookston Clay (Typic Haplaquept)	33.8	27.3	3.3	5.77	0.00
2	Brookston Clay (Typic Haplaquept)	21.1	42.3	3.1	7.33	0.79
3	Tuscola silt loam (Aquic Hapludalf)	18.5	56.9	3.9	6.60	0.16
4	Conestogo silt loam (Aquic Eutrochrept)	18.3	52.0	3.8	7.2	1.50
5	Conestogo silt loam (Aquic Eutrochrept)	17.9	53.4	3.4	7.17	2.04
6	Wattford loamy sand (Arenic Hapludalf)	6.4	10.4	2.9	6.40	0.00
7	Fox loamy sand (Arenic Hapludalf)	6.4	15.7	2.2	5.84	0.10

* organic matter

Measurement of dispersible clay

Soil cores were collected from the surface 0-7 cm layer at four randomly selected locations from each replicate at monthly intervals from May through to September in 1989, 1990, and 1991. The soil cores from each replicate were bulked and the 1-2 mm aggregate size fraction removed by sieving. The aggregates were prewetted on a wetting table at 1 cm suction for ninety minutes using deionized water and the dispersible clay measured using the Pojasok and Kay (1990) method.

RESULTS AND DISCUSSION

Assessment of the model

Analyses of the data suggested that there was no lag time for clay stabilization to commence subsequent to the introduction of forages on any of the soils. This is in contrast to the observation of a lag time, ranging from 0.72 to 1.05 yr, before changes in the stability of aggregates greater than 250 μ occurred on the same soils.

The R^2 for the best fit of Eq.[14] ranged from 0.48 to 0.84 (Table 2). The model was significant at $P < 0.05$ for each soil. Values of k ranged from 0.076 for soil 7 to 0.195 for soil 1. The half-life, $t_{1/2}$, for clay stabilization ranged from 3.55, for soil 1, to 9.12 yr, for soil 7, (Table 2). Values for Δq were negative indicating the sensitivity of DC to Θ at sampling decreased over time under forages. This is in contrast with the trends observed for wet aggregate stability of the same soils.

Table 2. Coefficients for the parameters in Eq.[14] for the different soils and the values for derived parameters.

Soil	Parameters							
	k (yr^{-1})	Δv	Δq	q_c	R^2	$t_{1/2}$ (yr)	$\Delta SC_f(\bar{\Theta}_f)$	$\frac{\Delta SC_f(\bar{\Theta}_f)}{DC_c(\Theta)}$
1	0.195	2.651	0.121	0.206	0.84	3.55	4.51	0.77
2	0.186	1.639	0.088	0.135	0.54	3.73	3.02	0.59
3	0.152	0.621	0.061	0.127	0.51	4.56	1.77	0.66
4	0.161	0.813	0.053	0.099	0.49	4.31	1.80	0.65
5	0.161	1.117	0.065	0.113	0.76	4.31	2.09	0.61
6	0.096	0.667	0.03	0.078	0.48	7.22	1.17	0.57
7	0.076	0.358	0.018	0.041	0.58	9.12	0.55	0.47
Mean	0.147	1.124	0.063	0.115	-	5.25	2.13	0.62

The maximum potential amount of clay stabilized, $\Delta SC_f(\bar{\Theta}_f)$, ranged from 0.55, for soil 7, to 4.51 g clay 100 g^{-1} of soil, for soil 1. The maximum potential amount of clay dispersed, $DC_c,(\Theta)$ i.e., from the corn treatment, is the pool from which clay stabilization occured. The $DC_c(\Theta)$ for the 7 soils was calculated using the regression equation provided by Rasiah et al. (1992). The ratio of $\Delta SC_f(\Theta_f)/DC_c(\Theta)$ represents the maximum fraction of the dispersed clay that can be stabilized by forages. The results presented in Table 3 indicate that from 47 to 77% of the dispersed clay potentially can be stabilized by forages.

Influence of soil properties

The stepwise regression procedure was used to establish relations between the parameters of Eq.[14] and soil properties, i.e, pedotransfer functions (Table 3).

Table 3. The results of the stepwise regression analysis for the coefficients of k, q_c, Δv, and Δq in Table 2 as dependent variables related to selected soil properties in Table 1.

Dependent variable	Intercept	Independent variable		Model	
		OM/Clay	pH	R^2(%)	P
q_c	0.3461	-0.3581	-0.0222	83	0.03
		Clay x OM x pH			
Δq	0.0092	0.00014		71	0.05
Δv	0.0584	0.00272		62	0.05
k	0.0663	0.00021		93	0.00

Values of k, Δv, and Δq increased with increasing clay and OM contents and pH of the soil. On the other hand, values of q_c increased with increasing clay and decreased with increasing OM content and pH.

Clay stabilization increased with time and this increase was larger at high clay and OM contents and pH. The $\Delta SC_f(\Theta_f)$ increased linearly with increasing clay and OM contents and pH. Values of $\Delta SC(\Theta)/DC_c(\Theta)$ also increased curvilinearly with increasing clay and OM contents and pH.

A reduction in tillage can lead to an increase in soil OM, thereby reducing clay dispersion. There is no reason, at present, to expect the role of soil properties on clay dispersion under reduced tillage would be different from that reported above although data on rate constants (Perfect et al., 1990) would suggest that the rate of change in SC_{net} may be slower. Further research is required to determine the persistence of reduction in clay dispersion if these soil are returned to corn production using conventional tillage.

Supplemental analyses (not reported) have shown that functions similar to the ones used in this report can be employed to describe the increase in stability of aggregates and the increase in hydraulic conductivity subsequent to the introduction of forages.

CONCLUSIONS

The semi-empirical model allowed the estimation of two important parameters, the maximum potential increase in clay stabilization, $\Delta SC_f(\Theta_f)$, that can be achieved in a soil, and the rate constant, k, which quantified the rate of clay stabilization. The analyses of the data collected over the three yr period indicated that more than one-half of the dispersed clay can potentially be stabilized by forages. The influence of forages on clay stabilization was greatest on fine textured soils and in soils with high organic matter content.

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TRAFFICABILITY OF MINERAL LOWLAND SITES AS RELATED TO SOIL HYDROLOGIC CONDITIONS

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ABSTRACT

The paper deals with the parametrization and quantification of relevant factors for assessing the soil trafficability. The aim is to develop a research tool which can be used in conjunction with soil water balance models to quantify real soil trafficability conditions for soil protection purposes.

The common practice to derive trafficability assessments from soil moisture or suction data only is insufficient. The following parameters at least are required to characterize the trafficability conditions adequately:
- Soil consistency resp. soil moisture degree/suction
- Soil density
- Degrees of tractive requirements resp. loads

As there are large moisture gradients from the soil surface to the bottom of the A-horizon in critical periods, it is necessary to divide this layer into 3 compartments (0-2 cm, 2-10 cm, 10-30 cm). A relational empirical matrix usable as a tool to compute the degrees of trafficability has been created and tested in some cases at different sites. It shows a fair to good accordance with the trafficability status under field conditions.

INTRODUCTION

Models of trafficability and workability of soils can be useful for decision support systems and general planning purposes. As these processes depend on the soil moisture status soil moisture models and border limits of soil moisture or suction for providing tillage processes are used to calculate the course of changes of trafficability and workability with time (1,2,3). Further criteria on soil status or construction of tyres are mostly neglected or not available for those general considerations.

The disproportion between the high performance of current soil water models on the one hand and the coarse criteria for trafficability on the other hand is obvious. This paper investigates which parameters are most suitable and practicable for providing reliable assessment of the trafficability status of cohesive soils.

MATERIALS AND METHODS

On 8 sites (Table1) located in the pleistocene and holocene areas East of Berlin, different parameters of soil moisture and strength status were analyzed and related to the actual degree of trafficability. The parameters are characterized by both qualitative assessment after visual-

tactile description of the topsoil (consistency state, wetness of the surface, status of the soil density) and measured data (water content by mass and volume, water tension, dry bulk density, cone resistance). The degree of trafficability was evaluated by a method basing on an assessment of the soil consistency state with consideration of indicators such as depth of wheel tracks (4). On the basis of previous results and experience three soil depths were considered, the soil surface (depth 0-2 cm), the upper topsoil (depth 2-10cm) and the lower topsoil (depth 10-30cm).
Different statistical procedures using the statistical package SPSSPC+ were applied to analyse the data sets. The regression analysis was used mainly to quantify the influence of the relevant parameters on the trafficability.

Table 1: Characteristics of the sites studied

Site No., Location	Parent material	Textural class (5)	Clay content %	Organic matter %	Liquid limit % by mass	Plastic limit % by mass	Field capacity % by volume
1, Seelow III	Holocene	Clay	51.6	4.6	68.0	37.0	32.0
2, Golzow	Holocene	Clay	48.6	4.5	66.0	35.6	31.0
3, Friedersdorf	Holocene	Clay loam	32.9	6.3	65.3	33.9	15.1
4, Seelow V	Holocene	Sandy loam	14.1	2.2	32.9	18.3	19.8
5, Sydowswiese	Holocene	Sandy clay loam	21.8	3.2	44.3	21.4	24.4
6, Diedersdorf	Young pleistocene	Sandy loam	13.1	1.6	25.6	14.6	22.9
7, Lüdersdorf	Young pleistocene	Sandy loam	17.6	1.7	27.7	15.6	25.5
8, Genschmar	Holocene	Sandy loam	18.0	2.6	38.8	18.3	21.7

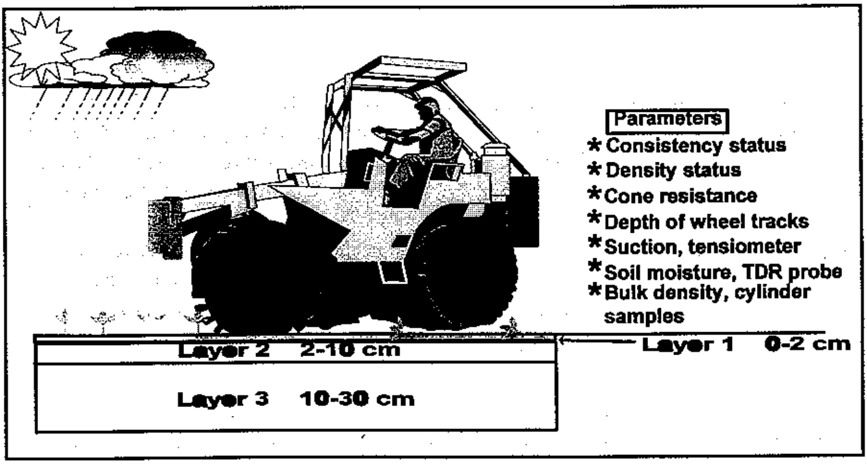

Fig. 1: Relevant soil depths and parameters

RESULTS AND DISCUSSION

Relevant parameters to characterize trafficability

The most reliable and significant parameters relevant for the trafficability status of the soil are those which characterize the soil structural and moisture status. These are relatively easy to evaluate or measure:
-the consistency of the upper 2cm (evaluation term)
-the density of the layer 2-10cm (evaluation term)
-the suction of the layer 2-10 cm (measured value or calculated, if suction > 1 Bar)
-the penetrometer resistance (measured value).
Some further measured significant parameters are:
-the consistencies of the layer 2-10 cm and the topsoil as a whole
-the densities of the layers deeper 2 cm
-the suction of the topsoil
-the saturation degree of the total pore space
-the degree of compaction related to the Proctor-density
Less reliable as expected are parameters characterizing the permeability or characterizing only the substrate or the absolute moisture status.
No single criterion is able to explain the trafficability status sufficiently. It is possible to calculate it with higher correlation coefficients from the main two or more relevant parameters .
Regression functions may be used for the estimation of the degree of trafficability:
$\text{Degree}=(0.760*\text{cons.}_{0-2})+(0.133*\text{cons.}_{2-10})-(0.33*\text{density}_{0-30})+0.5.$ $r^2=0.76$ (1)
$\text{Degree}=(0.747*\text{cons.}_{0-2})-(0.478*\text{density}_{2-10})+1.74.$ $r^2=0.85$ (2)
Additionally a tensiometer may be used by a person experienced with it:
$\text{Degree}= (0.800*\text{cons.}_{0-2})-(0.323*\text{density}_{2-10})-(0.021*\text{suction}_{2-10})+0.88.$ $r^2=0.90$ (3)
The degrees of consistency are expressed in steps of 1 (hard) to 6 (liquid) and the degrees of density in steps of 1 (low) to 3 (high) in accordance with table 2. The values of suction are in bars. The values of trafficability to be calculated are to be rounded to degrees 1 to 4 with intervals of 0.5.
The results show that trafficability in the field can be characterized by predominant evaluation terms or parameters which are very easy to measure. Directly measured variables such as dry bulk density, moisture content or variables based on it such as saturation degree or consistency indices do significant but not so closely reflect the actual trafficability status. Despite of the use of measurements with replications and data screening procedures a considerable amount of unexplained variance occurs.
On the other hand evaluation terms are relatively blurred and may contain subjective errors. The latter can be limited using international comparable framework evaluation schemes for example to derive consistency states in the field (4) .

Comparison of trafficability criteria

An empirical matrix to derive trafficability degrees from consistency states has been developed (6). To consider different states of the density of the topsoil this matrix is divided into three different density states. It is also available for six types of vehicles. Table 2 shows that part which is valid for a wheeled tractor at a medium requirement of traction force. .

Table 2: Degrees of trafficability as functions of topsoil consistency and density (Wheeled tractor, medium tractive force requirement)

Cons. state 0-2 cm	Cons. state 2-10 cm	Consistency state 10-30 cm																	
		Density 1 (low)						Density 2 (medium)						Density 3 (high)					
		1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
1 Hard	1	1	1	1	1	2	3.5	1	1	1	1	2	3.5	1	1	1	1	2	3.5
	2	1	1	1.5	2.5	3	4	1	1	1	2	3	4	1	1	1	2	3	4
	3	1	1	1.5	2.5	3.5	4	1	1	1.5	2	3	4	1	1	1	2	3	4
	4	1.5	1.5	2	3	4	4	1.5	1.5	1.5	2.5	3.5	4	1.5	1.5	1.5	2.5	3.5	4
	5	2.5	2.5	3	3.5	4	4	2.5	2.5	3	3	3.5	4	2.5	2.5	3	3	3.5	4
	6	3	3	3.5	4	4	4	3	3	3.5	4	4	4	3	3	3.5	4	4	4
2 Medium-hard	1	1	1	1	1.5	2	4	1	1	1	1	2	4	1	1	1	1	2	4
	2	1	1	1.5	2.5	3	4	1	1	1	2	2.5	4	1	1	1	2	2.5	4
	3	1	1	2	3	3.5	4	1	1	2	2.5	3.5	4	1	1	1	2	3	4
	4	2	2	2.5	3.5	4	4	2	2	2.5	3	3.5	4	2	2	2	2.5	3.5	4
	5	2.5	2.5	3	3.5	4	4	2.5	2.5	3	3.5	4	4	2.5	2.5	3	3.5	4	4
	6	3	3	3.5	4	4	4	3	3	3.5	4	4	4	3	3	3.5	4	4	4
3 Stiff-plastic	1	1	1	1	2	3	4	1	1	1	2	3	4	1	1	1	2	3	4
	2	1	1	1.5	2.5	3.5	4	1	1	1	2	3.5	4	1	1	1	2	3.5	4
	3	1	1.5	3	3.5	4	4	1	1	2.5	3	4	4	1	1	2	3	4	4
	4	2	2	3.5	4	4	4	2	2	3	3.5	4	4	2	2	2.5	2.5	4	4
	5	2.5	3	3.5	4	4	4	2.5	3	3	3.5	4	4	2.5	3	3	3.5	4	4
	6	3	3	4	4	4	4	3	3	3.5	4	4	4	3	3	3.5	4	4	4
4 Soft-plastic	1	1.5	1.5	2	3	3	4	1.5	1.5	2	3	3	4	2	2	2	3	3	4
	2	1.5	1.5	2	3	3.5	4	1.5	1.5	2	3	3.5	4	2	2	2	3	3.5	4
	3	2	2	3	3.5	4	4	2	2	3	3	4	4	2	2	3	3	4	4
	4	2.5	2.5	3.5	4	4	4	2.5	2.5	3	4	4	4	2.5	2.5	3	4	4	4
	5	3	3	4	4	4	4	3	3	3	4	4	4	3	3	3	4	4	4
	6	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
5 Very soft-plastic	1	2.5	3	3	4	4	4	2.5	3	3	4	4	4	3	3	3	4	4	4
	2	3	3	3.5	4	4	4	3	3	3.5	4	4	4	3	3	3.5	4	4	4
	3	3	3	4	4	4	4	3	3	4	4	4	4	3	3	4	4	4	4
	4	3	3.5	4	4	4	4	3	3.5	4	4	4	4	3	3.5	4	4	4	4
	5	3.5	3.5	4	4	4	4	3.5	3.5	4	4	4	4	3.5	3.5	4	4	4	4
	6	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
6 Liquid	1	3	3	3.5	4	4	4	3	3	3.5	4	4	4	3.5	3.5	3.5	4	4	4
	2	3	3	4	4	4	4	3	3	4	4	4	4	3.5	3.5	4	4	4	4
	3	3.5	3.5	4	4	4	4	3.5	3.5	4	4	4	4	3.5	3.5	4	4	4	4
	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
	5	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
	6	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4

Degrees of trafficability: 1 = Practicable; 2 = Limited practicable; 3 = Poor practicable; 4 = Not practicable

The test of the matrix with the current data set shows sufficient accordance or good accordance if only the alternative steps "trafficable" or "not trafficable" are beeing considered (Table 3). A trafficability degree of less then 1.5 is called "trafficable" and greater than 1.5 "not trafficable".
Compared with single criteria used by other authors (2,3) a distinct better evaluation of trafficability status will be possible.

Table 3: Comparison of predicted trafficability states using different criteria with observed data

				Percentage of correct predictions [1]		
Criteria	Border limit value	Relevant soil depth	Author	Trafficable	Not trafficable	Total
Suction	> 0.07 bar	30 cm	Michel,1989, (3)	88	26	56
Suction	> 0.06 bar	15 cm	Paul and de Vries, 1979, (cit. in 3)	93	23	57
Suction	> 0.1 bar	20 cm	Wösten and Bouma, 1985, (2)	90	30	60
Consistency state	=<Degree 3 (nonsticky)	30 cm	Michel, 1989, (3)	93	47	69
Consistency and density states	Matrix after table 2	30 cm	Müller, 1991, (6)	80	98	89

[1] Basis= Observed field data/status: 84 cases, 36 trafficable, 48 not trafficable.

The application of the matrix after table 2 in combination with soil water models to predict changes of trafficability requires close regressions between consistency states (assessment values) and consistency indices (computational values from actual soil moisture content and Atterberg limits). As problems especially with soils of weak plasticity may occur some additional work to quantify and verify these values should be done.

CONCLUSION

The results presented are empirical tools intended to improve the reliability of trafficability predictions using soil moisture models and its tests in the field. Their validity and applicability require some further testing.

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SIMULATION OF THE INFLUENCE OF PROTECTION MEASURES ON THE GENESIS OF EPHEMERAL GULLIES IN CULTIVATED CATCHMENTS.

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ABSTRACT

The effect of protection measures on concentration flow erosion was tested by simulation in a given catchment. Two groups of anti-erosion measures were tested: (i) changing of the runoff collector network combined with compacting the runoff concentration lines and setting grassed waterways, (ii) managing the soil surface state of fields by soil tillage. The simulations confirm the influence of the location of these anti-erosion measures. In the upslope part of the catchment, the main target is to reduce the aptitude of the soil surface to produce runoff, while in the downslope part, it is to increase topsoil cohesion, particularly along the runoff collector. The greatest reduction of erosion risk is obtained with grassed waterways along the main concentration lines combined with compaction of the secondary concentration lines.

INTRODUCTION

The aim of this study was to determine the effect of anti-erosion measures on the genesis of ephemeral gullies in a given cultivated catchment. The initiation of ephemeral gullies by concentrated flow is a function of a combination of topographical, pedological and agricultural factors (AUZET et al, 1990). The effect of anti-erosion measures must therefore be analysed by simulation, to take into account the interactions between these factors. The simulation procedure used in this study is based on an empirical model predicting the location and the volume of gullies initiated during winter (LUDWIG, 1992; LUDWIG et al, submitted).

MATERIAL AND METHODS

Simulation procedure

Modelling and characterizing the runoff collector network

The runoff collector network is assumed to be composed of all linear depressional features liable to concentrate overland flow and to guide the runoff towards the outlet of the catchment. This includes topographical depression lines and downslope field borders, provided they are occupied by a dead furrow or a headland (AUZET et al, submitted).

This network is split into segments having uniform land use and topsoil texture. Each segment is characterized by its slope gradient (SL), the soil susceptibility to scouring (SSS) and the size of upslope runoff-contributing areas (**RCA**) connected to it. The slope gradient (SL) is measured in the field. The soil susceptibility to scouring (SSS) is described by a score obtained by combining information on tillage, vegetal cover, topsoil texture and the occurrence of old filled-in gullies. The runoff-contributing area (**RCA**) is the upslope area assumed to produce runoff for most rainfall events occurring in winter, i.e. with low intensity. Such areas are defined by AUZET et al (1993; in press) as strongly crusted or compacted fields, areas having low infiltration capacity and surface water storage.

Rill volume estimation

The total volume of rills in a given catchment is estimated in four steps. First, the segment probability of no-erosion (**PWE**) is calculated by (LUDWIG, 1992; LUDWIG et al, submitted):

$$\mathbf{PWE} = (0.06\,\mathbf{RCA} + 0.92) / ((0.09\,\mathbf{SL} + 0.28)\,\mathbf{RCA} + 1) \qquad \textbf{(Eq 1)}$$

with **PWE** in frequency, **RCA** in ha and **SL** in %. The presence or absence of a rill is determined by randomly drawing a value **p** from a series of numbers uniformly distributed between 0 and 1: a rill is present when **p** > **PWE** and absent when **p** ≤ **PWE**. Second, for a segment associated with a rill according to the first step, the rill cross-sectional area (**CSA**) is estimated by:

$$\mathbf{CSA} = 1.93\,(\mathbf{RCA}^{0.65} \,.\, \mathbf{SL.}^{0.78} \,.\, \mathbf{SSS}^{1.04}) + \varepsilon \qquad \textbf{(Eq 2)}$$

with **CSA** in cm^2, **RCA** in $ha.10^{-2}$, **SL** in percent, **SSS** being a dimensionless grade and ε (random residual variable normally distributed with $\sigma\varepsilon = 808\ cm^2$) in cm^2. **Eq 1** and **2** were obtained for winter with a total cumulated rainfall of 320 - 480 mm and cumulated rainfall at intensities above that 10 mm/h of 60 - 90 mm. In such climatic conditions, the topsoil surface state of autumn sown crops (such as winter cereals) is strongly crusted in late winter and able to produce runoff.

Third, the rill volume of each eroded segment is calculated by multiplying the cross-sectional area (**CSA**) by the segment length, assuming a simple parallelepipedic shape. Fourth, the total volume of rills in a given catchment is obtained by summing the estimated rill volume of all segments composing the runoff collector network of the catchment. This procedure has been repeated 50 times with a random drawing of **p** and ε, providing a calculated average total volume of rills and its standard deviation.

Application of the procedure to a given catchment

Description of the catchment used

The simulation was conducted on a given elementary catchment, defined as an extreme upper ramification of the dry valley network (AUZET et al, 1993), located near Etretat, France (49° 40' latitude N, 0° 15' longitude E). This catchment, with a total area of 67.5 ha, is entirely cultivated by five farmers. Its topography is marked by a single main concentration line and by low slope gradients (below 10%). Its topsoil texture is very susceptibility to crusting (maximal clay content: 17.5%).

Simulated cases

Table 1 describes the simulated cases tested. Simulation **A** was build with the actual network (figure 1). This simulation was carried out assuming that the total catchment area was able to produce runoff. Thus, this simulation serves as reference to assess the effect of the anti-erosion measures. The following simulations were separated into two groups: (i) in one, the field surface state was managed by tillage operations, (ii) in the other, changes in field limits were combined with management of the waterways.

In the first group, two types of conservation tillage were tested: (i) increasing soil cohesion by direct drilling without tillage, (ii) decreasing runoff discharge by reduced tillage leading to a rough seed-bed surface. The effect of direct drilling was simulated by decreasing the score of **SSS** from 4 to 2 (MONNIER and BOIFFIN, 1986), without altering **RCA** (simulation cases **B**). Conversely, the effect of a rough seed-bed surface was simulated by reducing of **RCA**, without altering **SSS** (simulation cases **C**). Three spatial locations in the catchment (figure 2) were simulated for these two types of conservation tillage.

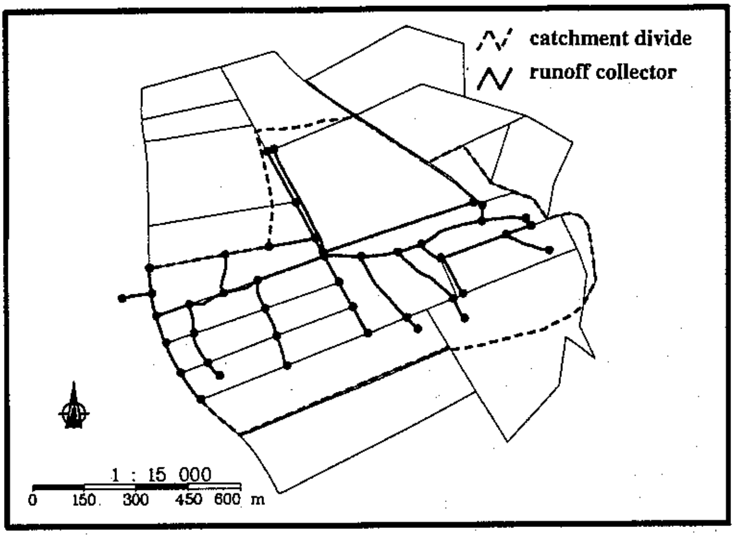

Figure 1: Actual runoff collector network.

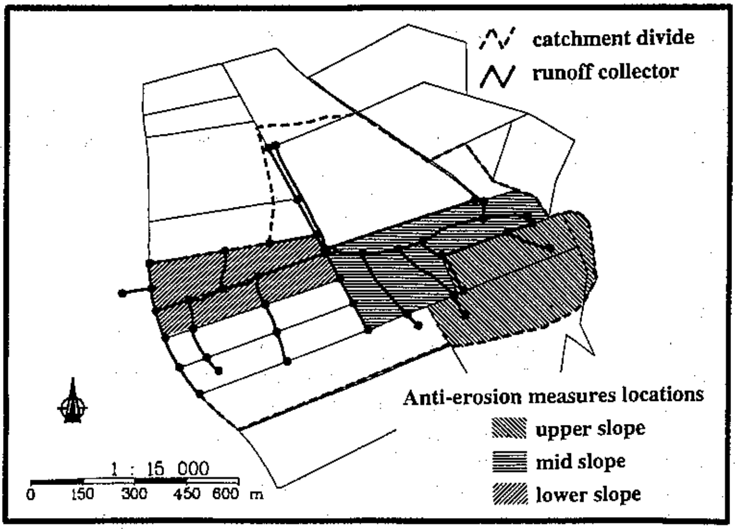

Figure 2: Locations of the direct drilling and rough seed-bed fields.

In the second group of anti-erosion measures, the network lay-out was modified by changes in the field limits. Two examples were simulated in cases **D** and cases **E**. Cases **D** needed only a small change of some field limits for one farmer (figure 3). Cases **E** needed a radical change of tillage direction and a redistribution of the land between farmers (figure 4). The simulations **D1** and **E1** were carried out without other anti-erosion measures, while **D2** and **E2** involved compaction (**SSS** = 1) or/and settlement of grassed waterways (**SSS** = 0) along the main concentration lines.

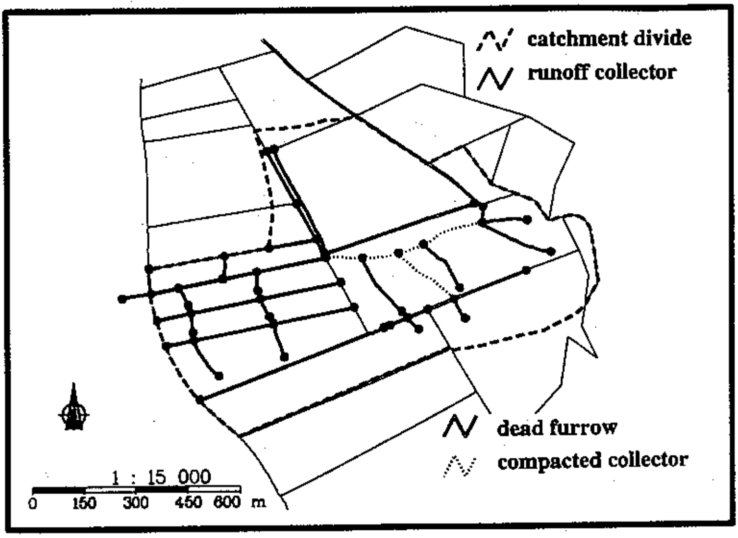

Figure 3: Modified runoff collector network by small changes in field limits.

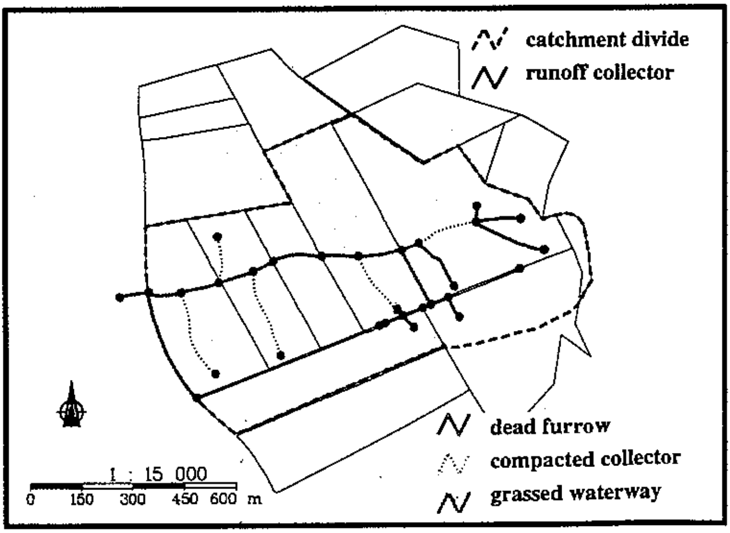

Figure 4: Modified runoff collector network by radical changes in field limits.

Table 1: description of the simulated cases.

Simulations	Total runoff contributing area	Field limits	Anti-erosion measures: Nature	Anti-erosion measures: Location
A	100%	Actual	None	
B1	100%	Actual	Direct drilling	Upper slope
B2	100%	Actual	Direct drilling	Mid slope
B3	100%	Actual	Direct drilling	Lower slope
C1	82%	Actual	Rough seed-bed	Upper slope
C2	82%	Actual	Rough seed-bed	Mid slope
C3	86%	Actual	Rough seed-bed	Lower slope
D1	100%	Small changes	None	
D2	100%	Small changes	Soil compaction	Along the main concentration lines
E1	100%	Radical changes	None	
E2	100%	Radical changes	Grassed waterways & soil compaction	Along the main concentration lines; Along the secondary concentration lines

RESULTS AND DISCUSSION

Table 2 gives the total rill volume for the catchment and the mean cross-sectional area for the most eroded segment for each simulation. This second variable is an indicator of traffic disturbance. If the cross-sectional area is higher that about 0.50 m^2, the rill cannot be crossed by agricultural machines.

Table 2: simulation results

Simulations	Total rill volume* (m^3)	Maximal CSA* (m^2)	Reduction of rill volume compared to simulation A
A	479 ± 87	0.71 ± 0.11	
B1	475 ± 87	0.71 ± 0.11	1%
B2	429 ± 83	0.71 ± 0.11	10%
B3	397 ± 73	0.36 ± 0.09	17%
C1	402 ± 72	0.62 ± 0.11	16%
C2	433 ± 88	0.62 ± 0.11	10%
C3	469 ± 86	0.65 ± 0.11	2%
B3 + C1	329 ± 61	0.33 ± 0.09	31%
D1	449 ± 90	0.40 ± 0.06	6%
D2	292 ± 73	0.21 ± 0.03	39%
E1	385 ± 78	0.40 ± 0.07	20%
E2	169 ± 52	0.20 ± 0.04	65%

(*: average value and standard deviation obtained after 50 repetitions)

The soil tillage conservation measures (simulation case **B** and **C**) had only a small effect on reducing concentration flow erosion, although they are considered to be very efficient against the rill-interrill type of erosion. The reduction of the erosion risk was particularly influenced by the location of these conservation measures. This reduction was maximal when the direct drilling was located lower slope (simulation **B3**), and while the maximal reduction was obtained on upper slope for the rough seed-bed (simulation **C1**). A combination of these two anti-erosion measures with their best spatial location (simulation **B3** + **C1**) decreased the mean rill volume up to 31% compared to simulation **A**.

Changes of field limits without other anti-erosion measures decreased the erosion risk. The reduction of mean rill volume was only of 6% for simulation **D1**. Indeed, although the runoff contributing area (**RCA**) was reduced for the segments forming the main concentration lines and thus decreasing their cross-sectional area (maximal **CSA** of 0.40 m^2), the increasing number of segments (41 to 45) increased the predicted erosion. In contrast, the great reduction in the number of segments (41 to 33) with simulation **E1**, particularly the segments with high slope value, decreased the erosion risk by 20%. When these changes of field limits were added to anti-erosion measures along the main concentration lines (compacted and grassed waterways), the predicted erosion was greatly reduced, particularly with simulation **E2** (decreasing of simulated rill volume by 65%).

CONCLUSION

Simulation of concentrated flow erosion was needed to test anti-erosion measures. The generally approved measures (i.e. direct drilling and rough seed-bed) have been found to be of little benefit. Their effects depended greatly on their spatial location inside the catchment. The greatest reduction was obtained by managing the runoff collectors, particularly with grassed waterways. Nevertheless, this measure has the disadvantage of disturbing traffic of field machines. Moreover, a full control of runoff concentration network often requires changes in field limits, sometimes radical ones. Thus, it is more advisable to enclose this type of anti-erosion measures at a re-allocation of land. Nevertheless, the installation of grassed waterways can be integrated in the environmental and agricultural European policy because this anti-erosion measure reduce both the erosion risk and the agricultural land area.

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CLIMATE CHANGE EFFECTS ON AUTUMN SOIL TILLAGE OPPORTUNITIES AND CROP POTENTIAL IN ENGLAND AND WALES

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ABSTRACT

A soil and agroclimatic model was used to calculate the number of machinery work-days during the autumn tillage period in England and Wales. These were mapped at a spatial resolution of 5 km x 5 km for a baseline climate (30 year average) and for selected climate change sensitivity tests. The sensitivity tests were chosen to reflect current best estimates of climate change relative to the climatic baseline and covered the range +/- 15% total annual precipitation and 1 to 4°C increases in average annual temperature.

The results suggest that future changes in precipitation, rather than temperature, will have the greatest effect on the number of machinery work-days. The improved tillage opportunities resulting from a 1 to 2 °C increase in temperature are negated by an annual increase in precipitation of 10%; this sensitivity test corresponding closely to the predicted best estimates of climate change for the year 2050.

Machinery work-days provide a direct input to a land evaluation model which has been used to assess the impact of climate change on land suitability for winter cereals. The distribution maps of suitability for England and Wales show that potential changes in soil tillage opportunities (defined by the machinery work-days) could have a marked effect on the ability of land to support winter wheat production.

INTRODUCTION

Global climate change, arising from the enhanced greenhouse effect, is expected to have widespread implications for agriculture (1). An important example of this is the potential impact of climate change on soil tillage. Agricultural field operations are strongly influenced by the weather in England and Wales, particularly during the autumn, when seed bed preparation and sowing are important activities. Over significant areas in England and Wales, the main restriction to growing winter cereals is that the soils are too wet for autumn cultivation. In some areas, this restriction causes yield reductions because of soil structural damage. In other areas, alternative, but less economic land uses may be preferred. The opportunities for soil tillage during the autumn can be defined by the number of machinery work-days (2). This paper attempts to predict; i) the effect of climate change on autumn machinery work-days, and ii) the effect of changing machinery work-days on the ability of land to sustain crop production.

METHODS

Modelling the number of autumn machinery work-days

The effect of climate change on the number of autumn machinery work-days (Wda) was estimated using a numerical model. The model, which has been fully documented elsewhere (3, 4), was developed specifically for spatial application over large geographical areas *viz.* England and Wales. The output of the model is a value of Wda, for each land unit evaluated, which expresses the number of days during the autumn tillage period (1 September to 31 December) when that land is considered workable. Climatic inputs to the model (temperature and precipitation) were perturbed in line with current best estimates of climate change for England and Wales (6) corresponding with the climatic sensitivity tests outlined in Table 1 (4). The model was applied to the dominant soil type within each 5 km x 5 km grid square affording spatial coverage of England and Wales. The method indicated regional variations in Wda across the two countries. For each pixel, Wda was modelled for the baseline climate *i.e.* a 30 year mean (1941-1970), and for each climatic sensitivity test relative to this baseline. Output from the model was used to generate maps.

Table 1 Climatic sensitivity tests for perturbed model inputs (3).

Sensitivity test	Temperature change (°C)	Precipitation change (%)
A (Baseline)	0	0
B	+1	0
C	+1	-10
D	+1	+10
E	+2	0
F	+2	-10
G	+2	+10
H	+4	0
I	+4	-10
J	+4	+10
K	+4	-15
L	+4	+15

Estimating the effects of Wda on crop potential

The modelled number of machinery work-days were used as inputs to a land evaluation model. In this model (5), Wda was combined with information describing crop drought stress (droughtiness) to estimate land suitability classes for winter wheat (well, moderate, marginal or unsuited) as indicated in Table 2 (5). The droughtiness index (mm) was calculated from the difference between the soil available water capacity (AP) and the moisture deficit (MD) and ignores water surpluses. MD is crop adjusted and derived from the potential soil moisture deficit (PSMD), thus:

$PSMD = \Sigma (PET - P)$

where, PET is the potential evapotranspiration and P is the precipitation (7). The relationships illustrated in Table 2 were determined from yield data for experimental farms (5). Application of the land evaluation model was used to indicate the influence of changes in machinery work-days, resulting from climatic changes, on land potential for winter wheat.

Table 2 The relationship between autumn machinery work-days and crop drought stress (droughtiness) in the estimation of land suitability classes for winter wheat (5).

	Droughtiness (AP - MD) (mm)				
Autumn machinery work-days	> 40	21 to 39	1 to 20	0 to -20	< -20
>80	well	well	well	moderate	marginal
50-79	well	well	moderate	moderate	unsuited
20-49	moderate	moderate	moderate	marginal	unsuited
<20	marginal	marginal	marginal	unsuited	unsuited

RESULTS AND DISCUSSION

Autumn machinery work-days

Figures 1 and 2 show the number of autumn machinery work-days for the baseline climate and when the baseline is perturbed by increasing temperature by 4 °C and decreasing precipitation by 10% (sensitivity tests A and I respectively in Table 1). The maps indicate that autumn tillage in most parts of England and Wales would benefit from the changed climatic regime illustrated in Figure 2, notably in western regions where currently the climate is the greatest contraint to soil tillage. However, an analysis of the results for all the sensitivity tests suggested that future increases in precipitation, rather than temperature, will have the greatest effect on the number of machinery work-days (4). The improved tillage opportunities resulting from a 1 to 2 °C increase in temperature are completely negated by an annual increase in precipitation of 10%; the sensitivity test (G in Table 1) corresponding most closely to the predicted best estimates of climate change for the year 2050 (6). This suggests there will be very little difference between the work-day opportunities at present and those for the middle of the next century (4). However, this result should not be considered as representative of a future world because:

1. The precision of current climate change predictions is open to question.
2. Sensitivity tests do not define an actual future situation because the arbitrary changes in temperature and precipitation are not physically related through normal climatological processes (8).
3. It is currently not possible to estimate the spatial (at a regional scale) and temporal (year-to-year and seasonal) variability in future weather patterns resulting from climate change. The sensitivity analysis demonstrated that the variability of future weather will have important implications for soil tillage opportunities.

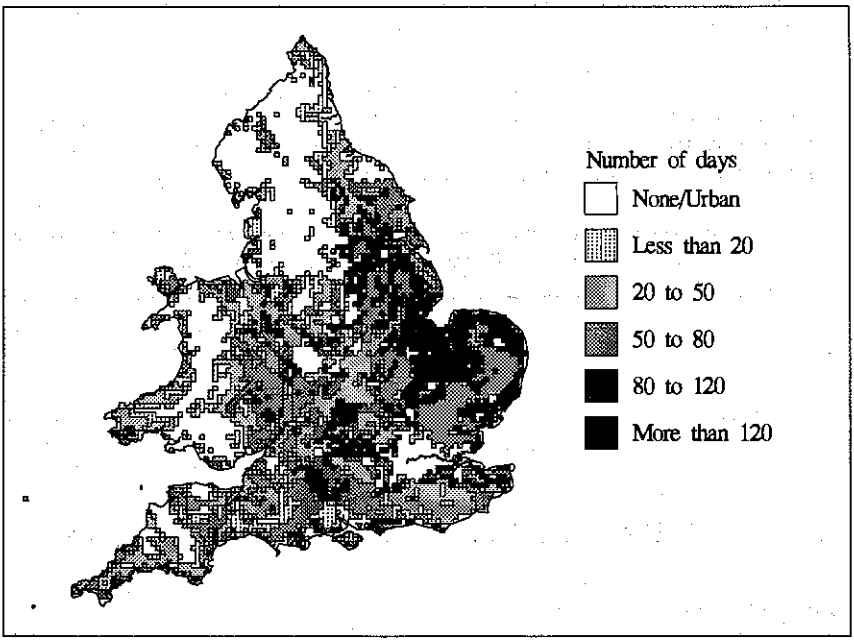

Figure 1 Autumn Machinery Workdays for the Baseline Climate

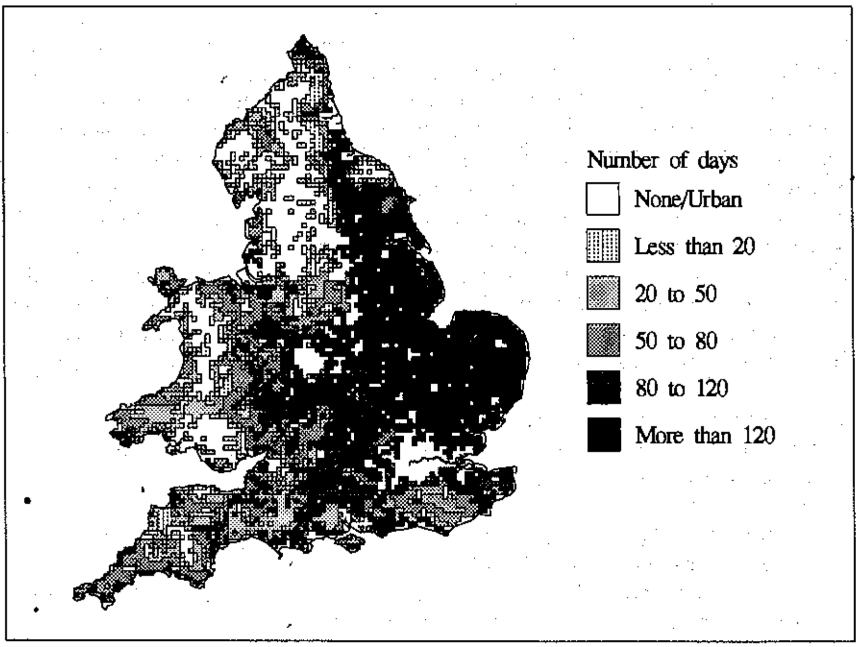

Figure 2 Autumn Machinery Workdays after a mean increase in temperature of 4 degrees C, and a decrease in precipitation of 10 percent.

Land suitability for winter wheat

The effect of machinery work-days on land suitability for winter wheat is offset by crop water stress; drier climatic conditions improve tillage conditions, but also result in greater crop water stress. This antagonism is emphasised by the climatic changes imposed through the sensitivity tests. Under drier climatic conditions it appears realistic to assume that autumn cropping in England and Wales would migrate from the currently drier east to the currently wetter west because soil tillage opportunities are improved in the west and drought stress is augmented in the east. However, if increasing temperatures are associated with increasing precipitation then conditions do not become drier and the geographical distribution of winter wheat potential is little changed from that at present. This latter hypothesis is the most likely outcome based on current best estimates of climate change (6), but with the reservations listed above for machinery work-days.

CONCLUSIONS

The model results for the climatic sensitivity tests suggest that:

- Changes in precipitation will have a greater effect on soil tillage opportunities in England and Wales than increases in temperature.
- Tbe potential to produce winter wheat in England and Wales will be improved if more soil tillage opportunities result from climate change. However, such an improvement could, in part, be offset by concurrent increases in crop water stress.
- A future changed climate, corresponding with current best estimates, will cause little difference in the number of machinery work-days and the distribution of suitable land for winter wheat in comparison with present conditions. This is because increased drying resulting from higher temperatures will be offset by increases in precipitation.
- The spatial (regional) and temporal (year-to-year and seasonal) variation in future weather arising from climate change is likely to have a more marked effect on autumn soil tillage opportunities and land suitability than changes in the mean conditions.

ACKNOWLEDGEMENTS

The research for this paper was funded by the UK Ministry of Agriculture, Fisheries and Food. We would like to acknowledge the helpful discussions of colleagues at SSLRC and ECU, particularly Dr. Peter Loveland, Prof. Peter Bullock, Prof Martin Parry, and John Orr for producing the mapped figures.

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MARKVAND. A PC-BASED SOFTWARE TO SUPPORT DECISIONS ON IRRIGATION IN DENMARK

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ABSTRACT

MARKVAND is a PC-software, which gives daily information on the timing and the amount of irrigation needed for a large group of agricultural crops. The MARKVAND system has been developed since 1988 by The Danish Institute of Plant and Soil Science in collaboration with The Danish Agricultural Advisory Centre. A priority module was implemented in the MARKVAND system in 1993. This new feature ranks the crops with respect to their economic net return of irrigation and thus recommends in which order the crops should be irrigated. Calculations in the priority module are based on model calculated yield increase due to irrigation, cost of irrigation and crop prices. The irrigation demand is calculated for a five days forecast period to help farmers in planning their activities.

The MARKVAND system includes models for crop development based on temperature sums, water balance based on the field and wilting capacity concept and empirical models for calculation of yield. Daily climatic input to the MARKVAND system is potential evapotranspiration and air temperature calculated in a national climate grid and precipitation measured at farm level. A seven days forecast for precipitation can be given as optional input. This is a valuable option which enables a better planning of irrigation and the possibility of saving water.

INTRODUCTION

The timing and need for irrigation has previously been based on local experience, simple rules and calculated figures for precipitation deficit (potential evapotranspiration minus precipitation). Supplemental irrigation is needed nearly every year on sandy soils to maintain a stable production level and at present about 15.000 irrigations plants are used to irrigate 15 % or 420.000 ha of the agricultural land (1). Along with the increased demand for water in different sectors of the society and the cost and income development in the agricultural production it was found necessary to focus on more efficient methods of irrigation management.

During the period 1988-1993 common efforts from The Danish Institute of Plant and Soil Science and The Danish Agricultural Advisory Centre resulted in the development of the MARKVAND system - a PC-based software to support decisions on irrigation management. The system has been released in two versions. In 1991 the system supported decisions on when and how much to irrigate to obtain maximum yield (2). A priority module was implemented in the MARKVAND system in 1993. This new feature recommends crops to irrigate ranked with respect to the economic net return of irrigation.

MATERIALS AND METHODS

Input of data

Climatic input to the MARKVAND system is daily potential evapotranspiration and temperature calculated in a climate grid with 44 grid squares covering Denmark. Potential evapotranspiration in the grid is calculated from a modification of Penman's (3) formula developed by Mikkelsen and Olesen (4). Additional daily climatic elements are on farm measurements of precipitation and irrigation as well as a seven days forecast of precipitation. Initially, data describing soils and crops have to be given as input to the system.

The water balance model

The water balance model in MARKVAND (2) runs on daily basis and is developed from other Danish conceptual models, cf. (5) and (6). The reservoirs and processes included in the model is described in Figure 1.

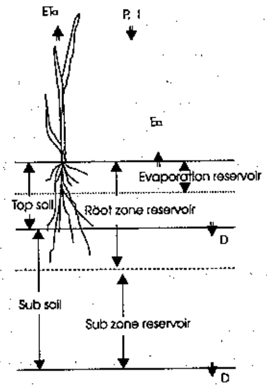

Figure 1. Reservoirs and processes in the water balance model of MARKVAND. Precipitation P, irrigation, I, actual evapotranspiration ET_a, actual evaporation E_a, drainage D.

Crop development (crop area index, root development and phenological growth stages) are calculated from temperature sums. The basic equations are given in (2).

The crop production model

Yield response to irrigation is calculated based on a modification of the stress-day model (7):

$$\left(1 - Y_a/Y_m\right) = k_y \sum \left(1 - E_{aT}/E_{pT}\right) \tag{1}$$

where Y_a and E_{aT} are the final yield and the daily transpiration respectively of a drought stressed crop while Y_m and E_{pT} are the corresponding variables for a fully irrigated crop. k_y is a drought sensitivity parameter which varies with crop species and developmental stage.

k_y was estimated from Danish irrigation experiments on agricultural crops where stress-days $(S_d = (1-E_{aT}/E_{pT}))$ were calculated on daily basis with the water balance model. Now consider a number of treatments with only one day of stress for which the drought sensitivity can be calculated from:

$$k_y = \left(1 - Y_a/Y_m\right)/S_d \tag{2}$$

then tbe calculated k_y-values can be fitted to a polynomial-function of the temperature sum (t_s) from emergence or onset of growth (for winter crops):

$$k_y = a + a_1 t_s + a_2 t_s^2 \; a_3 t_s^3 \tag{3}$$

Since most treatments in the applied irrigation experiments contained more than one day of stress we expanded Eq. 1 substituting the expression for k_y in Eq. 3 to describe the influence of multiple days of stress as:

$$\left(1 - Y_a/Y_m\right) = \sum_{i=1}^{n} S_{di}\left(a + a_1 t_{si} + a_2 t_{si}^2 + a_3 t_{si}^3\right) \tag{4}$$

where i is day-numbers between emergence and harvest. A similar multiplicative model reads:

$$Y_a/Y_m = \Pi_{i=1}^{n}\left(1 - S_{di}\left(a + a_1 t_{si} + a_2 t_{si}^2 + a_3 t_{si}^3\right)\right) \tag{5}$$

These statistical models were fitted to data with the parameters in Eq. 4 estimated by the linear least-squares procedure REG of SAS (8) and the parameters in Eq. 5 by the non-linear procedure NLIN. A detailed description of the modelling is given in (9).

The priority module

The developed crop production models were in collaboration with the Danish Agricultural Advisory Centre implemented in MARKVAND in a priority module. The module takes into account the cost of irrigation and the actual prices on crops enabling an output showing a recommended plan of irrigation presented for a five day forecast period. Within this period the crops are ranked in order to their economical net return of irrigation. The system can be applied from March to November and is adapted to the Danish growth conditions for the following crops: peas, potatoes, grass, spring and winter barley, winter wheat, winter rye, beets, spring and winter rape and corn.

RESULTS AND DISCUSSION

The water balance model

A comprehensive test of the water balance models is given in (2) and (9).

The crop production model

Using Eq.'s 4 and 5 and irrigation experiments mainly from Jyndevad Research Station it was possible to estimate drought sensitivity parameters for the crops shown in Table 1. For all crops except fodder beets the multiplicative model, Eq. 5 gave the best description of data. Only positive values of k_y were accepted which restricted the validity of the yield response to only a part of the growing season defined as the temperature sum interval listed in the Table 1 with start T_s and end T_e.

Table 1. Estimated parameters a, a_1, a_2 and a_3 in the drought response function k_y in MARKVAND. The standard error of regression (root mean square error) RMS_e on $1\text{-}Y_d/Y_m$ and the number of experimental treatments used in the analysis n. Validity interval of the function from temperature sum T_s to T_e (°C).

Crop	a	a_1	a_2	a_3	RMS_e	n	T_s	T_e
winter barley	-7.767E-02	5.317E-04	-4.524E-07	0.0	0.137	9	171	1004
spring barley	-9.265E-02	2.825E-04	-1.507E-07	0.0	0.113	25	424	1451
winter wheat	-7.437E-05	1.204E-04	-7.263E-08	0.0	0.085	43	1	1656
potatoes, m. late	5.188E-03	8.713E-05	-6.111E-08	0.0	0.050	26	0	1482
winter rape	-7.965E-02	3.353E-04	-2.131E-07	0.0	0.106	26	292	1281
spring rape	-7.083E-02	2.779E-04	-1.561E-07	0.0	0.091	37	309	1472
peas	-1.376E-01	8.264E-04	-9.817E-07	3.257E-10	0.070	44	220	1226
rye grass	1.340E-02	8.463E-06	-7.040E-09	0.0	0.034	14	0	2106
fodder beet	-5.660E-02	6.660E-05	-7.738E-09	0.0	0.064	15	957	2594

Table 1 shows standard error of regressions varying from 3 % for grass to 14 % for winter barley. This error can in another way be described in scatter plots as deviation from the 1:1 line when simulated yield is plotted against measured yield, cf. Figure 2.

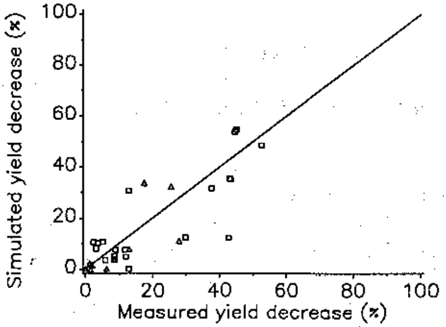

Figure 2. Calculated relative yield decrease plotted against measured for pea. Data from experimental stations Jyndevad (□) and Borris (△).

For several crops - among others corn, late potato and winter rye - sufficient experimental data were not available for development of parameters with sufficiently accuracy.

The relative error when using the crop-water production functions for prediction of yield could be argued for some crops to be unacceptably high, especially when a small yield decrease is estimated. However, it was concluded in (10) that the developed crop-water production functions shown in Table 1 were of satisfactory accuracy and suitable to be implemented in a priority module in MARKVAND.

The priority module

The functional relationships enabling ranking of irrigation needs can be presented as in Figure 3. The figure shows yield decrease per stress day calculated in kr/ha for spring crops. The functions are calculated for temperature sums at Jyndevad in 1992 and 1992 prices. From these relationships irrigation in mid June would be recommended in the order potatoes, peas, spring barley and spring rape if the same level of drought was exposed on all crops.

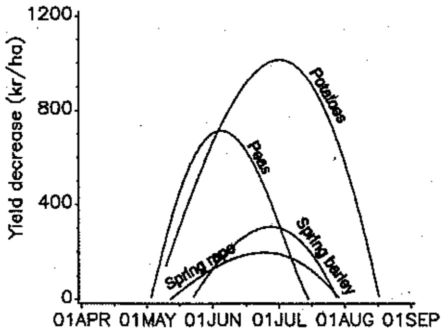

Figure 3. Drought sensitivity for spring crops expressed as decrease in gross economical yield per stress day. Functions calculated from 1992 crop prices and temperature sums in 1992 at Jyndevad.

The output introduced to the end user is presented in Figure 4 and 5.

Figure 4 shows the output screen in MARKVAND with the recommended irrigations ranked from 1 to 3. The economic net return is shown in Figure 5.

MarkVand Recomandation of irrigation OverWr 25maj92

Recommended irrigation for the farm in grid element 12
Department of agrometeorology, Research Centre Foulum
8830 Tjele, phone 86-89991800

	mon	thu	wed	thur	fri
Precipitation forecast	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Evapotransspiration forecast	**5.0**	**5.0**	**5.0**	**5.0**	**5.0**

Field name	Area ha.	Crop	Irrigation amount (mm) mon		thu	wed	thur	fri	Deficit mon	sat
1	2.0	Spring barley	**35**	3					31	12
2	2.0	Winter wheat	**40**	2					36	12
3	1.0	Potatoes, m.							10	14
4	1.0	Spring rape							28	38
5	2.0	Peas							7	9
6	2.0	Fodder beet							9	12
7	2.0	Winter barley	**40**	1					36	12
8	2.0	Corn							6	7

Planned area for irrigation, ha	**6.0**
Irrigation amount, kbm	**2310**
Irrigation, time	

Abondon with Esc - F4 irrigation amounts - F5 print - F9 graphics

Figure 4. Recommended amount and order of irrigation calculated with MARKVAND.

CONCLUSION

A PC-based software MARKVAND including submodels on crop development, water balance and economic return of irrigation for agricultural crops has been developed. Experience from use at farm level indicates that MARKVAND is a useful tool for supporting decisions on allocation of a limited irrigation capacity.

MarkVand Recomandation of irrigation OverWr 25maj92

Recommended irrigation for the farm in grid element 12
Department of agrometeorology, Research Centre Foulum
8830 Tjele, phone 86-89991800

	mon	thu	wed	thur	fri
Precipitation forecast	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Evapotransspiration forecast	**5.0**	**5.0**	**5.0**	**5.0**	**5.0**

Field name	Area ha	Crop	Net return for irrigation (kr/ha) mon	thu	wed	thur	fri	Deficit mon	sat
1	2.0	Spring barley	**-165** 3					31	12
2	2.0	Winter wheat	**295** 2					36	12
3	1.0	Potatoes, m.						10	14
4	1.0	Spring rape						28	38
5	2.0	Peas						7	9
6	2.0	Fodder beet						9	12
7	2.0	Winter barley	**418** 1					36	12
8	2.0	Corn						6	7

Planned area for irrigation, ha **6.0**
Irrigation amount, kbm **2310**
Irrigation, time
Abondon with Esc - F4 irrigation amounts - F5 print - F9 graphics

Figure 5. The economical net return obtained by irrigation calculated with MARKVAND.

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THE USE OF ONFARM METEOROLOGICAL DATA FOR RESOURCE UTILIZATION IN SUSTAINABLE CROP PRODUCTION

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ABSTRACT

During the period 1993 to 1995 an onfarm meteorological weather station, the Hardi Metpole, will be demonstrated in operational use in research projects, and in collaboration with the Danish extension service in field trials. Results from 1993 are given on intrafield variation in temperature and relative humidity microclimate compared to similar data from the nearest standard meteorological station. Calculations of a disease index for sporulation and infection for yellow rust in winter wheat is compared with use of macro- and microclimate data.

1. INTRODUCTION

Integrated crop production may be considered a technical component of a low input sustainable farming system, where some 'chemistry' is being substituted by 'knowledge' (Mikkelsen, 1993). Specified principles and technical guidelines have been set up for integrated production by IOBC (IOBC/WPRS, 1993). To ensure an optimal disease and pest control with low impact on the environment, computer-based decision support systems will be a necessary tool in the integrated farming systems. In Denmark such a system has been developed (Secher, 1991; Murali, 1991). Seasonal and actual weather has major impacts on crop growth, nutrient utilization, disease development, farm operations etc. Detailed weather data are therefore expected to be implemented in the Danish DSS on plant protection. As ordinary meteorological networks are sparse in many countries, onfarm measured weather data may be used as input data for models aimed at fx optimizing the use of fertilizers and pesticides in integrated crop production.

During the period 1993 to 1995 an onfarm meteorological weather station, the Hardi Metpole, will be demonstrated in operational use in research projects, and in collaboration with the Danish extension service in field trials. A short presentation of the metpole and results on intrafield variation in microclimate in winter wheat will be given in this paper.

2. MATERIALS AND METHODS

2.1 The Hardi Metpole

The Hardi Metpole is a meteorological weather station for onfarm use (Figure 1). Every 30 minutes collected data are transferred by radio signals via a receiver at the farm to a PC. Current and historical basic meteorological data and calculated variables like temperature sums, precipitation sums etc. can be presented as tables, graphs and printouts (Høstgård, 1993).

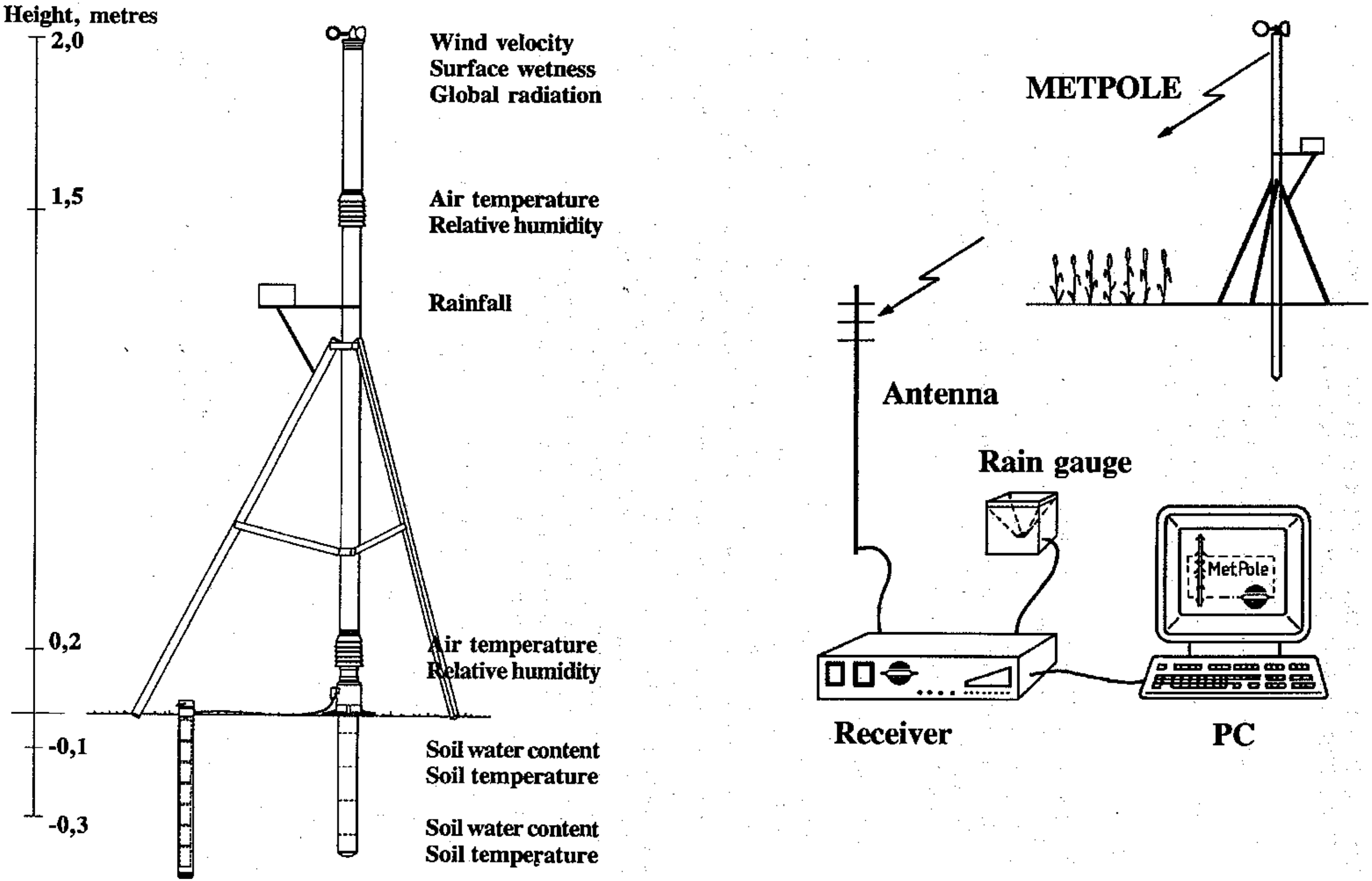

Figure 1. The Hardi Metpole and metpole system.

A Rain gauge is mounted on the metpole and a similar one is placed at the farm. The transmission distance is up to 5 kilometres in Denmark, but longer distances may be obtained in other countries were legislation on the power of the transmitter is different.

2.2 Intrafield variation in microclimate

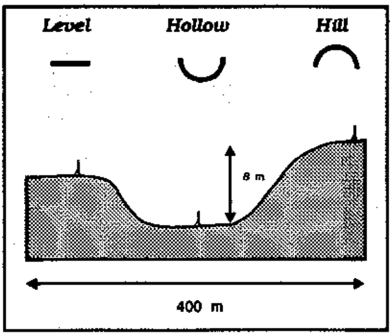

Figure 2. Positions of Metpoles in winter wheat field at Vindum.

The metpole measures both micro- and macroclimate (Figure 1). To get an idea of the magnitude of intrafield variation in microclimatic conditions, nine metpoles were placed at three locations in an undulated field with winter wheat at Vindum Overgaard (Figure 2). The positions were "level", "hollow" and "hill" , in a triangle with distances of about 300 m between the metpole groups.The metpoles were placed in untreated plots, and during the season disease assessments were made for powdery mildew, yellow rust and Septoria spp. in these plots. Differences in the microclimatic conditions were compared to disease development. The cultivar Haven has a low susceptibility to yellow rust and powdery mildew under Danish conditions, but is less susceptible to Septoria spp..

Calculation of disease index

To calculate the risk for development of yellow rust based on historical weather data, an index was used as described by Secher (1993). This index results in a daily calculated value from 0 to 5, where 0 indicates no risk and 5 indicates a high integrated risk of infection following a period of sporulation. As a simple index general for a number of diseases, the number of hours with temperatures between 13 and 20 °C and relative humidity over 85 % was calculated. Index calculations were compared for metpoles located in the field and for a metpole placed at the meteorological station at Research Centre Foulum, about 10 kilometres away. In the same way index calculations with macroclimatic and microclimatic data from the field were compared.

3. RESULTS

The overall meteorological conditions during the season are given in Figure 3. June was cold and dry, and July was cold and wet compared to normal conditions for Foulum 1961-90. The accumulated index for yellow rust during the period May 15 to July 15 is given for metpole data in the field at Vindum compared to calculations with metpole data from Foulum (Figure 4). In Figure 4 A, the accumulated index calculated with data from Foulum has a differing course at the end of the period when compared with index calculated with Vindum data.

With a range of the daily calculated rust index from 0 to 5, the indices can be used to evaluate the risk of development of yellow rust. Since attacks older than one latency period can be observed in the field, only index calculations within one latency period are of interest. For Danish summer conditions, one latency period is equivalent to 10 to 15 days (Tsum of 195 °C, T_b= 0°C). A difference between observations on less than one risky day within one latency period indicates only a minor difference, but a difference equivalent to several risky days can lead to misinterpretations when using indices to evaluate disease risk. The difference

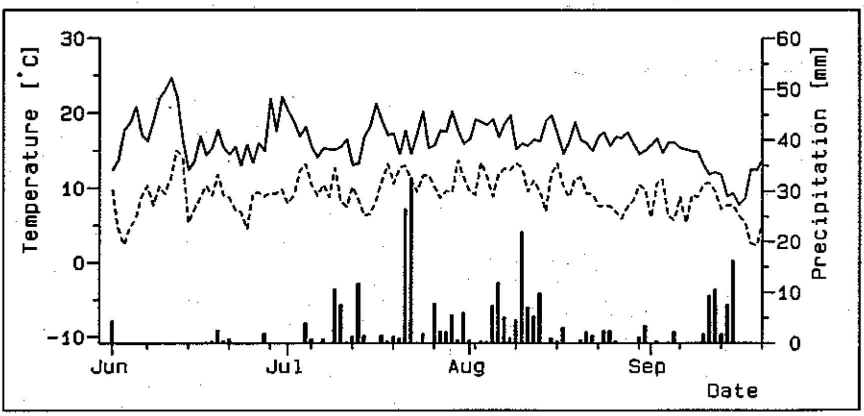

Figure 3. Meteorological conditions during the period June to September 1993 at Research Centre Foulum. Daily maximum and minimum temperature [°C] and Precipitation [mm] are given.

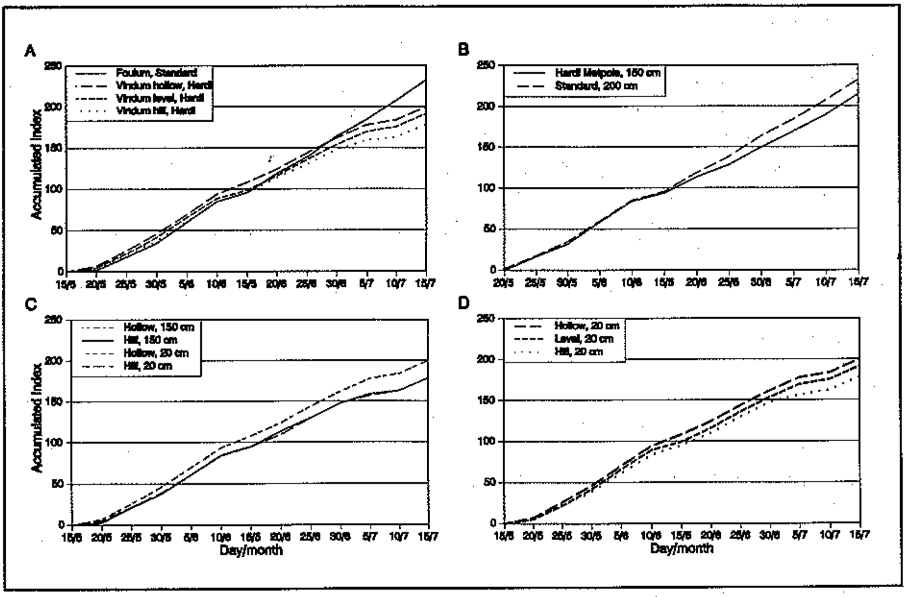

Figure 4. Comparisons of accumulated daily index for yellow rust calculated from various weather stations. FS= Foulum standard weather station. HM= Hardi Metpole: A=FS compared with 3 positions of HM (150 cm) at Vindum field. B=FS compared with HM (150 cm) at Foulum. C=HM (20 cm) and HM (150cm) at hollow and hill positions in Vindum field. D=HM (20 cm) at 3 positions in Vindum field.

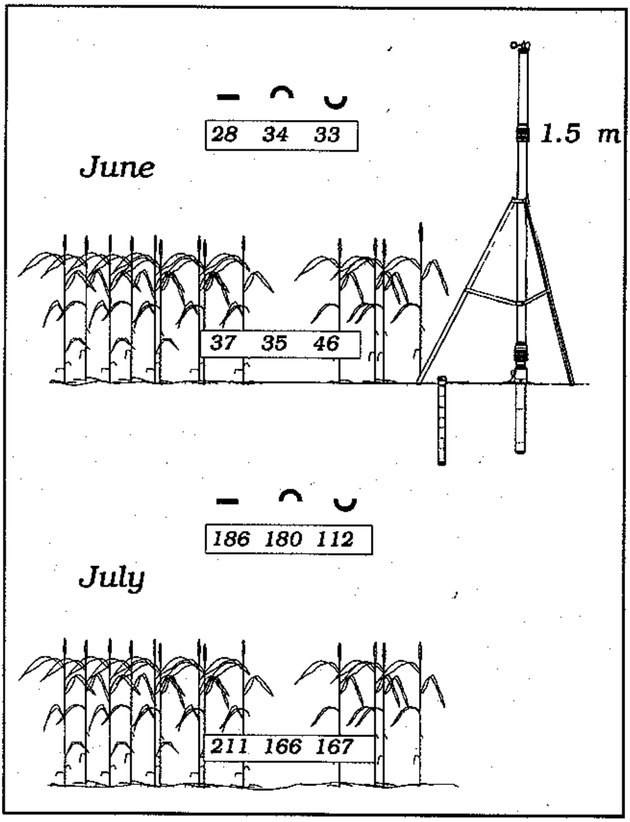

Figure 5. Number of hours when temperature is between 13 and 20 °C and relative humidity is above 85 %. Calculations are made for 1.5 and 0.2 metres measurements. Above: Total hours for June. Below: Total hours for July. Signatures refer to "Level", "Hill" and "Hollow" (refer to Figure 2).

between Foulum and Vindum data shown in Figure 4 A at approximately 35 units (7 risky days) when going one latency period back from July 15 therefore, indicates that a longer distance between the field and site of weather measurements can lead to misinterpretations

A calculation of a general leaf disease index showed 5-6 times more "risk hours" in July than in June (Figure 5). The difference in "risk hours" between localities were insignificant in June, but there were recorded more "risk hours" at level field and relative less "risk hours" in the hollow part of the field. Fewer "risk hours" in the hollow part of the field may be due to lower temperature at night conditions (Figure 5).

No disease at all was observed in June, and because of early senescence according to the dry weather in June, only a few plants were registered with weak attacks of Septoria spp.

4. DISCUSSION AND CONCLUSIONS

Models based on meteorological data for calculations of evaporation, plant growth, disease development etc. are normally developed with ordinary meteorological data, and data from standard height is therefore required as input variables for these models. Models based on results from laboratorium and climate chamber research may use microclimatic data as input variables, taking the intrafield variation into account. The results from this investigation show minor differences in calculations of two leaf disease indices, using either data from above the crop (1.5 m) or microclimate data (0.2 m). On the other hand the metpole takes regional and local characteristics into account, which are important for fx plant protection purposes (Schrödter, 1983). Much work is needed to implement the proper use of instruments like the metpole into decision support systems.

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EFFECT OF TRACK - TYPE TRACTOR IN SOIL TILLAGE SYSTEM

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ABSTRACT

A field experiment was conducted to evaluates of a new-generation agricultural track-type tractor PPT-130. This tractor was developed within the framework of the military conversion program in the Heavy Industry Plant, Martin, Slovakia. The technical parameters (engine power 130 kW, operating weight 12 540 kg) indicate that the machine is suitable for a wide range of field operations. The values of bulk density, shear strength and penetration resistance as well as the yield response of chosen crop - grain maize, was used for evaluation of the effect of given tractor in soil tillage.

INTRODUCTION

Recently, the crawler tractors within the system of mobile power units played an important role in Slovak agriculture. The tractive performance, the relatively simple track system and a wide range of utilization possibilities on agricultural farms were considered a significant advantage. Over the period of last ten years the general tendency in utilization of the tractors has developed in favour of wheeled tractors. The reason was mainly the wide utilization in agricultural transport as well as in field operations where a mobile power unit is needed (either for field works or for public transport). In accordance with the requirements to eliminate the negative effects of technogenous factors on soil, track-type tractors of a new generation were develped in the 80-ies. In connection with this tendency research of the effects of new agricultural track-type tractors on soil has been conducted (ERBACH, D.C. et al. 1988, JORI, I.J. et al. 1991, NOZDROVICKY L.- MIHAL P., 1991).

MATERIAL AND METHOD

The experiment examined the possibilities of utilization of the track-type tractor PPT-130 (producer Heavy Industry Plant, Martin) within the technological operations of the plant production in an agricultural farm. The research was conducted in two levels:

- examination of effects of the track-type tractor on selected soil properties and effect of selected crop growing - grain maize (Zea mays L.),
- evaluation of possibilities of the track-type tractor utilization in different field operations during the year.

Description of the selected agricultural farm

The experimental testing of the track-type tractor PPT-130 was conducted in the Cooperative Farm Salgovce, district Topolcany. This farm has an area of 1900 ha of agricultural land, 1739 ha represent arable land. In the crop rotation system individual crops represent following areas: winter wheat 2429 ha, spring barley 268 ha, triticale 73 ha, spring wheat 50 ha, grain maize 130 ha, rape 150 ha, ensilage maize 180 ha, lucerne 190 ha, sugar beet 180 ha. Average plot areas represent 30 - 40 ha. The experiment was conducted on a orthic luvisol, parent soil material - loess.

Testing object

The testing object was the agricultural track-type tractor PPT - 130 (prototype number 01), Figure 1, suitable for ploughing, subsoiling, seedbed preparation and sowing and further field works.

Technical parameters of the track-type tractor PPT-130:

- max. operating weight	12 540 kg
- weight of unsprung parts	2 050 kg
- overall tractor length	6 500 mm
- overall tractor width	2 650 mm
- tractor height	3 350 mm
- contact track length	2 700 mm
- track gauge	2 025 mm
- track width	500 mm
- clearance height	400 mm
- max.tractive speed	23,5 $km.h^{-1}$
- static unit pressure	37 kPa
- engine power	130 kW at 2200 rpm^{-1}
- max. torque moment	710 N.m at 1480 rpm^{-1}
- max. specific fuel consumption	220 $g.kWh^{-1}$
- number of gears (forward/backward)	32/16
- PTO shaft	540/1000 rpm^{-1}
- type of steering system	differentially combined directional device with hydrostatics

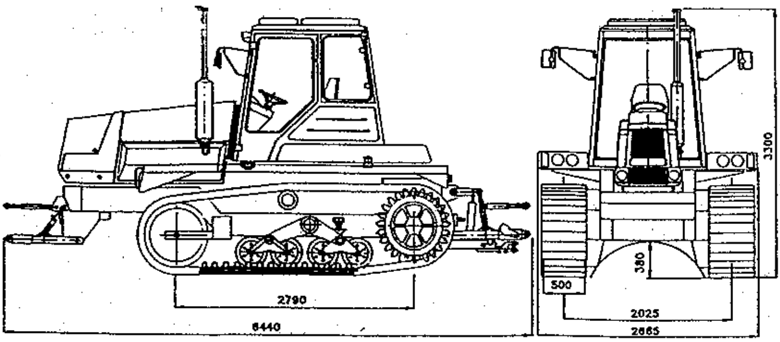

Fig. 1 Agricultural crawler tractor PPT - 130

Field experiment variants

The agricultural track-type tractor PPT-130 was tested in the technology of grain maize growing on an area of 36 ha in the following variants:

- variant A: seedbed preparation and sowing were carried out with machines based on the wheel-type tractor system
- variant B: seedbed preparation and sowing were carried out with machines based on the track-type tractor system

Within the variant B two subvariants were evaluated observing the effect of maize seed sowing inside the crawler tractor track (variant B_1) and outside the crawler tractor track (variant B_2).

For the evaluation of the effects of above mentioned technologies of grain maize growing the attention was concentrated on:

- sowing parameters (sort of maize, emergence, sowing depth, sowing-seed, straight-line sowing),
- characteristic features of emerged plants (number of emerged plants),
- characteristic features of crop yields (number of harvested plants, number of cobs), dimensions of cobs, biological harvest).

Measurement technique used

The effects of the track-type tractor were evaluated according to the changes of following soil properties:

- soil bulk density - measured with the Kopecky physical cylinders,
- soil penetration resistance - measured with the recording penetrometer,
- shear strength in soil - measured with the hand-vane tester Pilcon Edeco.

All measurements of individual quantities were repeated and statistically processed using the Grubbs test to achieve the necessary authenticity and accuracy of results.

RESULTS AND DISCUSSION

The effects of the track-type tractor PPT-130 on selected soil properties and the effect of selected crop growing

According to the introduced methodology the effect of passes of the agricultural track-type tractor PPT-130 on selected physical and mechanical soil properties mainly on grain maize growing was observed.

The track-type tractor PPT-130 was compared with the wheel-type tractor ST-180 with similar engine power and dual-wheels.

Figure 2 shows the soil penetration resistance after trafficking with the track-type tractor PPT-130 and the wheel- type tractor ST-180. Figure 2 shows the evidence that an unloaded track-type tractor after trafficking causes lower increments of soil penetration resistance in individual depths of the soil profile.

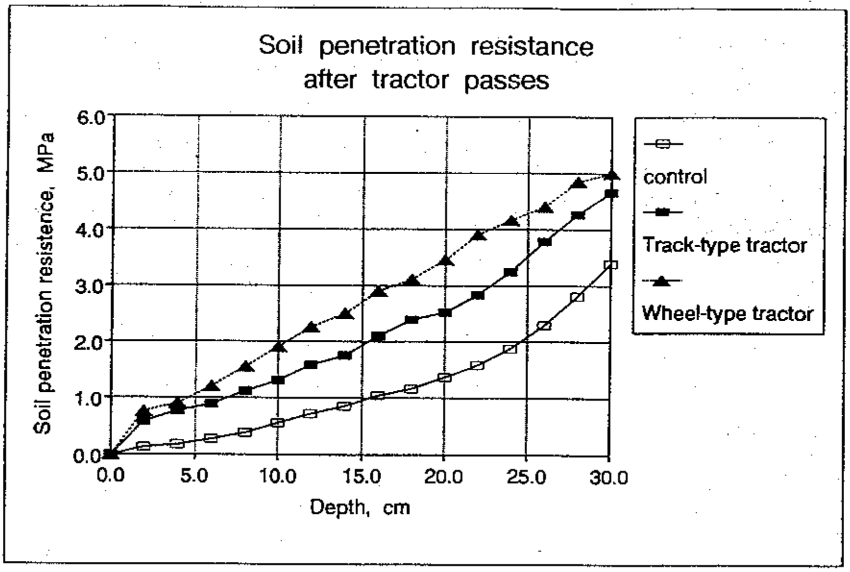

Fig. 2 The changes of the soil penetration resistance after passes of the track-type tractor PPT-130 and wheel-type tractor ST-180

It is generally stated that the considered track-type tractor in comparison with the wheel-type tractor of similar power shows half an increment of soil penetration resistance. The effects of the track-type tractor on soil confirm the measuring results of soil bulk density and shear strength showed in the following Table 1.

Changes of the soil properties due to the tractor passes

Table 1

Soil parameter	Control	Track-type PPT - 130		Wheel-type ŠT - 180	
		value	index	value	index
Moisture content (%)	21,73	20,51	-	21,75	-
Bulk density ($g.cm^{-3}$)	1,46	1,65 * 1,72	113,0 117,8	1,71 z 1,74	117,1 119,1
Shear strength (kPa)	28,30	48,89 * 57,32	172,3 202,5	51,69 z 59,59	182,6 210,6

(* - tractor loaded by implement LEMKEN Kompaktor K 600 A)

Some changes occurred after the loading of the considered track-type tractor by multipurpose implement for seedbed preparation LEMKEN Kompaktor K 600 A. All indices of the physical and mechanical soil properties were changed (Table 1). Due to the acting of the soil resistance has occured the force which caused relieving the front part of the tractor. This results in a reduced contact area and an increased pressure and in an overall change of the contact between the tracks and the soil. The result of these changes is an increased soil compaction. The track-type tractor was examined also from the point of its utilization in the grain maize growing technology. The results in the Table 2 indicate that the utilization of the track-type tractor shows the highest grain yields (variant B_2).

The effect of the cropstand parameters and yield response of grain maize

Table 2

Parameter	Variant		
	A	B_1	B_2
Number of emerged plants ($ps.ha^{-1}$)	73 333	73 000	73 666
Number of harvested plants ($ps.ha^{-1}$)	72 848	71 666	72 420
Biological yield ($t.ha^{-1}$)	7,08	6,95	7,94

Analysis of possibilities of utilization of the track-type tractor in field works.

The examined effects of the track-type tractor on soil properties and crop yields approve the utilization of this particular type of mobile power unit in technological systems of plant production.
The Cooperative Farm Salgovce where the prototype of the tractor was tested has an area of 1739 ha of arable land.
The crop rotation system of individual crops gives the following possibilities of utilization of the track-type tractor PPT-130:
- primary tillage (ploughing)
- seedbed preparation,
- sowing of cereals.

The tractor is used mainly for seedbed preparation. This can have a positive effect on soil condition during the vegetative period. Semi-mounted multipurpose implement LEMKEN Kompaktor K 600 A is ideal for these purposes due to its efficiency and system of hitching to the tractor. In the overall system of field implement hitched to the tractor PPT-130 played an important role also the swing plough VP-5. This plough has the required technical and operating properties. The track-type tractor can be used also for sowing. Sowing of cereals is considered using the sowing machine AMAZONE RP-AD 302. Figure 3 shows the overall survey of the structure of utilization of the track-type tractor during a year.

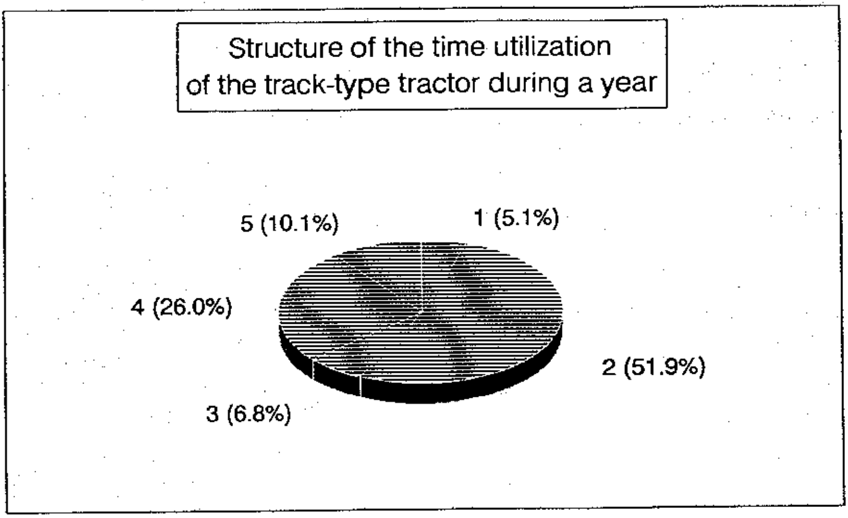

Fig. 3 Structure of the utilization of the crawler tractor during a year (1-deep ploughing, 2-ploughing, 3-disking, 4-seedbed preparation, 5-sowing)

CONCLUSION

Current trends in the technical development of plant production (increasing of productivity and elimination of negative effects of machines on soil) show good prospects in using efficient track-type tractors within the system of mobile power units. The track-type tractor PPT-130 showed good tractive properties and positive effect on soil during experimental field experiments. The main utilization of this type of tractor can be seen in primary tillage (ploughing) up to 675 hours per year and in seedbed preparation using the multipurpose implement - more than 300 hours per year.

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DIRECT DRILLING THROUGH STRAW RESIDUES

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ABSTRACT

The recent ban on straw burning in UK, coupled with a reduction in farming profits, has re-kindled interest in direct drilling oilseed rape and cereals. Field experiments were conducted through a range of straw and climatic conditions using a drill with novel cross-slot openers to assess its potential for UK conditions. Following some modifications, the drill performed satisfactorily, however, plant numbers and vigour diminished over the winter period. This effect was particularly prevalent in areas where straw lay on the surface and could have implications for the direction of future direct drilling development.

INTRODUCTION

The problems associated with the production of oilseed rape and cereals in UK in the absence of straw burning can be severe. Establishment and subsequent crop performance is often erratic, particularly on heavy soils. Current drilling equipment is not designed to work through large quantities of straw. Tillage sufficient to overcome the straw problems, is expensive and often produces undesirable side effects. Poor seed beds are common in drier and wetter years following significant tillage and there is a risk of moisture loss and delayed germination.

These problems have prompted the need to further develop direct drilling techniques and equipment capable of establishing oilseed rape in the presence of straw.

A cross-slot direct drilling opener capable of operating through heavy straw or trash has been developed by Baker and Choudhry at Massey University, New Zealand, ((1), (2) & (3)) - see Fig. 1.

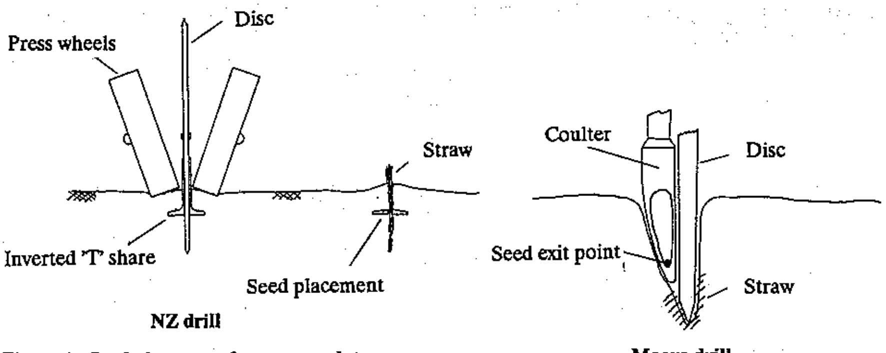

Figure 1. Seed placement from cross-slot openers

The successfull adaptation of this principle to more difficult UK conditions, could provide the following benefits:-

1) Reduced establishment time and costs.

2) Increased reliability of establishment in dry years due to minimum soil moisture loss from the seed bed.

3) Increased opportunity for crop establishment within the optimum period.

4) Reduced soil erosion on coarse textured soils.

5) Reduced leaching of nitrates.

MATERIALS AND METHODS

The major objectives of the study were as follows:-

1) To assess the performance of the cross-slot drill opener when operating through straw residues.

2) To evaluate the influence of straw and stubble condition on opener performance, identifying the most desirable straw/stubble conditions and opener design.

3) To develop establishment systems for oilseed rape in the absence of burning under a range of field conditions.

Six cross-slot openers were imported for the 1991/92 season. In addition, a Moore Uni-drill was used alongside the New Zealand drill for comparative purposes - see Fig. 1. Two types of experimental study were conducted:-

1) Short term establishment studies to identify the major soil, straw and operational factors influencing opener performance.

2) Comparative trials, in conjunction with the Agricultural Development and Advisory Service (ADAS) to monitor crop performance from seeding through to harvest.

The experiments were carried out at four heavy clay soils of the Evesham (x 2), Worcester and Denchworth soil series. The straw and cultivation treatments on each site were selected to span the range of straw conditions likely to be found in field situations, ranging from stubble only through chopped and spread to standing and laid straw - see Table 1.

Table 1. Treatments and site conditions.

Evesham Soil Series:

Treatment	Drill	Loose straw t/ha	Stubble height (mm)	Loose straw length (mm)
Baled, DD*	NZ**	2.7	115	
Chopped & spread, DD	NZ	8.4	115	75
Spread unchopped, DD	NZ	8.4	115	200
Stripped, DD	NZ	3.1	370	
Laid, DD	NZ	3.5	480	
Double straw, DD	NZ	13.5	115	75

* DD = Direct Drill
** NZ = New Zealand

Denchworth, Evesham and Worcester Series:

Treatment	Drill
Baled, DD	NZ
Chopped & spread, DD	NZ
Chopped & spread, DD	Moore
Baled DD	Moore
Double straw, DD	NZ
Chopped, plough, cultivate, drill	Accord
Chopped, disc x2, drill	Accord
Chopped, dyna drive x2 drill	Accord
Chopped, broadcast, power harrow 2.5 cm	-

The following assessments were made:-

Pre-drilling
a) Straw yield, chop length, stubble height
b) Soil moisture content
c) Cone penetration resistance (0-100 mm, 20 mm increments)

Post drilling
a) Plant emergence within permanent quadrats. This was assessed in terms of maximum number to emerge (total emergence) and time to 50% emergence (rate of emergence).

b) Straw cover and depth in each quadrat. This was assessed on a 0 to 10 straw index scale.

0 = rooted stubble only
7 = 100% straw cover
10 = 100% cover to > 100 mm depth

c) Final yield

RESULTS AND DISCUSSION

Performance of the New Zealand direct drill

a) The disc coulter worked well through all types of straw and straw condition. Straw was often forced into the vertical disc slot.

b) Seed placement in wing opening to side of vertical disc slot was achieved.

c) In dry conditions:-
Performance was very satisfactory providing coulter penetration was adequate. Some penetration problems were encountered under very hard dry conditions (common to all disc type openers).

Seed depth control was adequate although it was necessary to set the depth adjustment to drill rather deeper than optimum to avoid shallow seed placement in local surface depressions.

d) Wet conditions:
The following problems were encountered:-
(i) Straw and soil pick-up on disc and press wheels resulting in seed disturbance, loss of depth control and drill blockage.

(ii) Skidding of press-wheel in loose surface conditions causing straw blockage.

(iii) Soil and straw pick-up on 2nd row press wheels causing blockage and reduced seeding depth.

Modifications to the New Zealand direct drill

The following modifications were made to the drill:-

(i) Press wheel scrapers added; satisfactory under compact surface soil conditions, unsatisfactory when loose.

(ii) Press wheels removed; soil consolidated after drilling using a light furrow press.

(iii) New design for disc scrapers; functioned well.

Direct Drilled Plots

(a) Drill coulter penetration
Cone penetration resistance was monitored at 40 and 80 mm depth for the Moore and New Zealand direct drills respectively. Penetrometer readings lay in the range 10 to 38 and 20 to 50 kgf at the Evesham and Denchworth sites respectively. Consequently, some penetration problems were experienced by the Moore Uni-drill. No significant influence of penetration resistance was found on either total emergence or rate of emergence.

b) Soil moisture content
Soil moisture content was found to significantly influence rate of emergence, the time for 50% emergence increasing form 9.3 to 11.6 days between irrigated and non-irrigated plots. Moisture content had little influence on total emergence.

c) *Straw index effects*
Quantity of straw cover had a significant effect on both total emergence and rate of emergence as shown in Table 2.

Table 2 The influence on straw index on total, and rate of, emergence.

Straw Index	Total emergence (number of plants/1 m^2)		Rate of emergence (number of plants/1 m^2)	
	Mean	SD	Mean	SD
0 - 3	107.7	38.8	9.9	3.1
4 - 6	95.6	35.3	10.2	1.7
7 -10	79.7	36.2	11.4	2.3

d) *Influence of straw treatment*
As shown in Table 3, the overall condition of the straw had minimal influence on both rate of, and total, emergence. Plant numbers were, however, significantly higher, and the time for 50% emergence, lower, on the baled plots compared with straw covered plots.

Table 3 The effect of straw treatment on total, and rate of, emergence.

Maximum No. of plants/m^2			Time (days) to 50% of maximum		
Mean	SD	Treatment	Mean	SD	Treatment
		Irrigated			
83.1	27	Double	10.4	2	Double
90.3	20.2	Standing	9.7	1.6	Chop + spread
90.8	30.2	Spread	9.6	1.8	Laid
95.6	20.2	Chop + spread	8.9	1	Standing
104.8	38.5	Laid	8.5	1.2	Spread
141.	31.	Baled	6.9	0.8	Baled
		Unirrigated			
67.6	32.5	Chop + spread	12.9	1.8	Double
67.6	35.6	Standing	12.	1.4	Standing
72.9	56.5	Laid	11.8	2.4	Chop + spread
80.2	23.2	Double	11.7	1.6	Laid
103.9	34.2	Baled	11.5	3.1	Baled
115.	27.7	Spread	11.3	0.8	Spread

e) *Comparison of direct drills*
No significant effect on crop performance could be determined when comparing the New Zealand and Moore direct drills.

Comparison of direct drilling with other establishment techniques
The gravimetric moisture content in the seed bed ranged from 6% in the ploughed plots to 22% in the direct drilled plots. Treatment means for various establishment techniques are presented in Table 4.

Table 4 Treatment means for various establishment techniques.

Maximum No of plants/m^2			Time (days) to 50% of maximum		
Mean	SD	Treatment	Mean	SD	Treatment
93.2	26.3	Tine	29.7	2.3	Plough
93.7	16.9	Disc	18.6	3.1	Disc
98.1	57.2	Moore, chopped	16.8	1.8	Tine
104.8	25.6	B/cast, ph	16.1	4.6	Moore, chopped
[113.0]	43.2	NZ, double	[16.0]	2.9	NZ, double
119.3	39.0	Plough	15.2	1.9	B/cast, ph
143.0	41.0	Moore, baled	[13.2]	1.6	NZ, baled
143.0	36.2	NZ, chopped	11.6	2.4	NZ, chopped
[157.5]	33.6	NZ, baled	11.6	2.0	Moore, baled

[treatments not randomised within overall design].

With the exception of the Moore drill working in thick chopped straw, where there was considerable variation both within and between plots, total emergence and rate of emergence following direct drilling was favourable when compared with the tillage treatments. Differences in rate of emergence between treatments are illustrated in Figure 2. The advantage of direct drilling over tillage in this dry year is very apparent.

Subsequent crop development
After a promising emergence and establishment in September, problems of reducing plant numbers and vigour started to develop in December. This damage, which in some cases resulted in total loss of crop, was much more prevalent in areas where straw lay on the surface.

Figure 3 shows the results of the assessment just before flowering in April, when crop conditions was recorded relative to surface straw cover. The crop condition assessment is an amalgam of plant numbers, vigour and height. The strong influence of straw cover on crop condition is very obvious.

The reasons for this straw effect are not fully understood. The major factor, however, was pigeon damage, the pigeons apparently having a strong preference for landing, walking and feeding on straw covered areas. Having chosen particular feeding areas, they appear to return to those same areas and keep the crop grazed down throughout the season. The pigeon does not seem to like long standing stubble and this could be one condition to be aimed at and explored further for direct drilling. Other factors contributing to the problem could be anoxic zones occurring during straw breakdown and a possible deleterious effect of straw cover on frost damage.

Final yield.
Yield results for the Evesham and Worcester sites, are presented in Table 5.

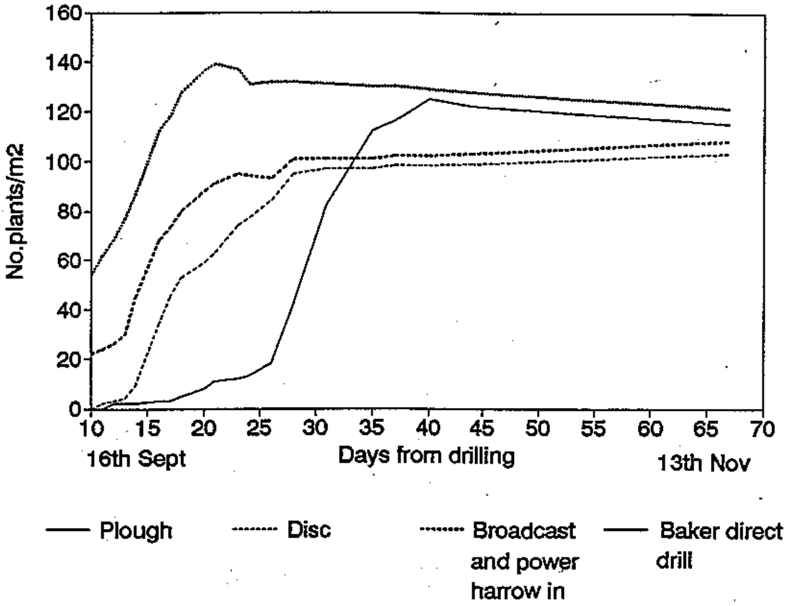

Figure 2. Establishment of oilseed rape, Denchworth soil series.

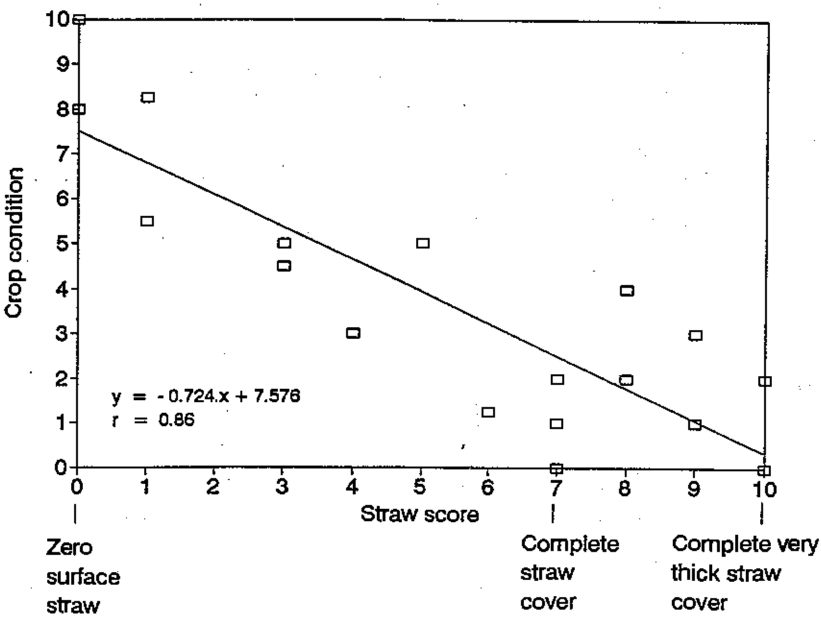

Figure 3. Crop condition against straw score, Denchworth soil series.

Table 5 Oilseed rape yield results

Treatment	Evesham plants/m^2	Evesham t/ha	Worcester plants/m^2	Worcester t/ha
Chopped, plough, drill	65	1.41	81	2.58
Chopped, disc x2, drill	50	1.20	74	2.85
Chopped, tine x2, drill	23	1.37	50	2.89
Chopped, b/cast, power harrow	16	1.09	44	2.70
Chopped, direct drilled (Moore)	6	0.79	24	2.66
Baled, direct drilled (Moore)	48	1.27	37	3.18
Chopped, direct drilled (NZ)	4	0.82	23	2.99

It is interesting to note that despite worryingly low plant numbers on direct drilled plots, the relative yield is high particularly on baled plots.

CONCLUSIONS

After modifications to suit UK conditions, the New Zealand drill openers proved capable of working under dry conditions through a range of straw and soil conditions, but experienced some penetration problems where soil strength was high.

Plant emergence following direct drilling was as good as, or better than that following other establishment techniques involving cultivation with significant benefits in terms of rate of emergence in the dry conditions which prevailed during the establishment period.

The severe reduction in plant numbers and condition, over the winter period, was most marked on areas with a thick straw covering. The reason for this straw related effect is not entirely clear, however, possible explanations include:-

1) a preference of pigeons for walking and feeding on straw

2) toxins released from straw on breakdown

3) straw preventing beneficial heat loss from soil affording frost protection

4) straw reducing the rate of freezing of the upper profile promoting frost heave and root damage

The results of this work suggest that, where possible, cereal straw should be removed from the soil surface prior to direct drilling.

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Direct Drilling - Optimizing of Openers
Current State and First Results

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ABSTRACT

"Direct Drilling" means the placement of seeds in untilled soil. Direct drilling enables a sustainable protection against soil erosion and compaction. In addition energy and labour costs are saved.

There are many different technological solutions for direct drilling machines because the requirements vary from country to country. But, mainly they can be distinguished between machines with tine openers and disc openers. Besides these, there are some special solutions such as spade planters.

Direct drilling machines with tine opener and disc openers were tested. The soil disturbance, the seed placement, the soil-seed contact, and the influence of straw residues were determined. It was shown that a satisfactory sowing quality is still difficult to achieve in no-tilled and residue covered soil especially in wet conditions and with heavy grain straw residues.

INTRODUCTION

Direct drilling or no-tillage is the direct application of seeds into the soil without any prior tillage. It has a long tradition in the semi-arid areas of North America and Australia and it is successfully practised in many other countries. In Germany direct drilling is still under investigation. However, there is already a growing interest by farmers to test and practise this technology.

Direct drilling has many important advantages. The soil is very well protected against wind and water erosion (1,2). The water losses by evaporation are minimized, which is very important in dry areas (3). Direct drilling also promotes high biological activity, excellent soil structure and a good water infiltration rate (4,5). Furthermore, the risk of soil compaction and wheel tracks caused by heavy machines is reduced (6). Beside, the ecological and agronomical advantages of direct drilling, the energy and labour requirements of direct drilling systems are much lower compared to conventional tillage (1). Along with those advantages, there are currently several disadvantages in using direct drilling. The management of direct drilling systems is more difficult than the conventional tillage systems (7). Weeds and slugs, mice or other pests can cause severe problems (8). Moreover, satisfactory sowing quality is still difficult to achieve in no-tilled and residue covered soil especially in wet conditions and with heavy grain straw residues.

Direct drilling openers are divided into two main groups, namely: the disc openers and tine openers (9). Besides the common disc and tine openers, there are, however, some special systems like spade openers or seeders for rape seed or catch crop, which are mounted on a header of a combine harvester.

MATERIAL AND METHODS

Field experiments were conducted to investigate the sowing quality of a tine opener and a single disc opener machine. The experimental site was situated south of Stuttgart, Germany on a commercial farm. It was a loamy soil. The previous land use was winter wheat. The straw was baled and removed on one half of the experimental site. On the other half the straw was chopped and remained on the field. Table 1 shows the experimental conditions.

Table 1 Experimental Conditions.

Moisture content (wet base)	22.0	%
Bulk density (dry)	1310	kg/m^3
Pore volume	50.2	%
Stubble site:		
Average of stubble height	14.5	cm
Chopped straw site:		
Stubble height (mean)	12.0	cm
Length of chopped straw (mean)	5.0	cm
Chopped straw (dry mass)	4853	kg/ha

On the experimental sites three strips of 100 m length and one machine working width (3 m respectively 2.5 m) were sown with spring barley for each variation. The variations were three working speeds (5 km/h, 10 km/h, 15 km/h) and two sowing depths (3 cm, 8 cm). The seeds were dyed with blue colour to make it easier to find the seeds in the soil.

A special multiple-penetrometer according to TESSIER (10) was used to measure soil disturbance and compaction. This penetrometer consists of 11 load cells, each equipped with a steel probe of 150 mm length and a diameter of 2 mm. The load cells are mounted on to a frame to push the probes into the soil manually. A displacement sensor measures the displacement of the probes. The penetration forces and the displacement were registered by a portable data logger.

A special soil plane according to BREITFUSS (11) was developed to determine the sowing depth and the amount of incorporated straw. The plane cleared away 1 cm thick soil layers and collected the soil of each layer. These samples were washed through a sieve to determine the number of seeds and the amount of incorporated straw in each sample.

Moreover, large soil samples were taken, dried and cut into 5 cm thick slices. X-ray images were taken of the slices to determine areas of different soil density. Afterwards the slices were investigated manually to find out the position of the seeds and the soil-seed contact.

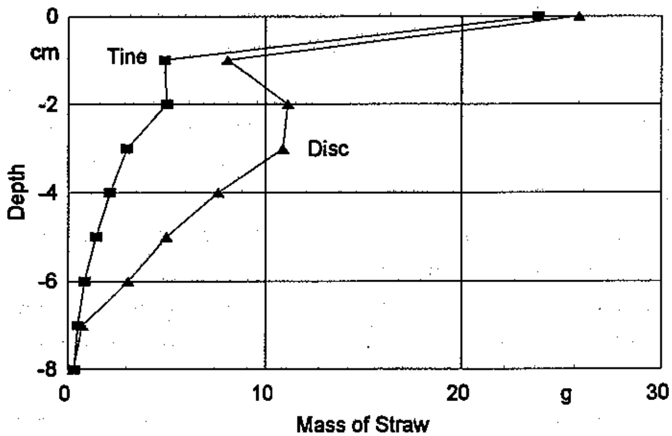
RESULTS AND DISCUSSION

Soil disturbance and soil compaction of each variation was measured by the multiple penetrometer. The results were compared with the x-ray images. The working speed showed no significant influence. The sowing depth influenced the sizes of the furrow only but not the shape. Disc openers caused less soil disturbance compared to tine openers. Tine openers caused a wide V-shaped furrow without any soil compaction. The furrow caused by the single disc opener was a small slot with a minimum of soil disturbance. In addition to this there was some sidewall compaction.

Low soil disturbance minimizes the emergence of weeds and water losses. In soils with high silt or clay content the seeding furrows remain open because there is not enough loose soil to close the furrow. The heavy soil disturbance caused by tine openers improves the infiltration, aeration and warming up in the sowing furrow. Disadvantages are higher emergence of weeds and water losses.

The incorporation of straw was investigated with the soil plane. Picture 1 shows typical results from the site covered with chopped straw. On the stubble site the tendencies were the same, but the amount of incorporated straw was lower.

Picture 1 Amount of incorporated straw by a tine and a disc opener.



Tine openers incorporate significantly less straw than disc openers. However, tine openers tended to pile up straw on the soil surface and tended block up sometimes. Disc openers never block and they leave a plane soil surface but they push straw into the sowing furrow and place the seeds in the straw. Most straw is located around the seeds. This causes a poor emergence and a poor crop growth because the soil-seed contact is low and phytotoxic substances originated from the decay of the straw residues affect the seedlings (12). Additionally, contaminated straw (plant diseases) can infect the seedlings' and local nitrogen immobilization can weaken the crop. It is not possible to determine the amount of incorporated straw on x-ray images, but they show the position of the straw in the soil.

The seed placement was determined with the help of the soil plane. In addition the soil samples were investigated manually to find out the position of the seeds and the soil-seed contact. In contrast to CHOUDHARY (13) it was not possible to determine the position of the seeds by x-ray images.
There is no significant influence of straw residues on the sowing depth distribution of tine openers. However, straw residues clearly change the sowing depth distribution of disc openers. The average sowing depth and the part of seeds in the adjusted sowing depth decrease, i.e. straw residue significantly decreases the sowing quality of disc openers.

Most seeds are positioned in the middle of the sowing furrow. Disc openers push straw residues into the furrow and place the seeds in the middle. This means there is no soil-seed contact, which causes poor crop growth. Tine openers place the seeds in the middle of the furrow, too. However, the soil-seed contact is better because the amount of incorporated straw is lower and the seeds are surrounded by a mixture of loose soil and straw.

CONCLUSION

Until now a satisfactory sowing quality by direct drilling machines is difficult to achieve in no-tilled and residue covered soil. Disc openers tend to push the straw into the furrow while tine openers pile up straw residues and tend to block up. Especially in wet conditions and with heavy grain straw residues the sowing quality is usually unsatisfactory. In Germany such conditions are quite common. High precipitation in fall and spring very often cause wet and soft soils during the sowing time. Yields of more than 8 t grain per hectare leave heavy straw residues. So, technical improvements are necessary to increase the direct drilled acreage.

Direct drilling is an important contribution to sustainable agriculture. Statistics show that the direct drilled area is increasing in many countries. Environmental and economic reasons and laws will surely force the farmers all over the world to switch over to such systems. If the technical problems of direct drilling can be solved and more experiences can be gained, it is expected that the direct drilled area will increase considerably in the future.

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IMPLEMENTS FOR PLOUGHLESS SPRING SEEDBED PREPARATION

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ABSTRACT

This paper deals with the results obtained from three field trials using various types of implement for one passage seedbed preparation without previous ploughing for spring crops in South-East Norway. The objectives were to compare various types of implement in relation to energy consumption, aggregate size distribution, working depth, ability to incorporate straw residue, and seed emergence after seeding. Seven various types of implement were tested in three different trials, and within each trial there were three replications of each implement run in replicated block experimental design. The experiment was carried out in the spring of 1993. The implements used were rotory cultivator, rotory harrow, Dynadrive, disc harrow with soil packer, disc harrow with crumbler roller, tine harrow, and a combined tine and disc harrow with soil packer. The results show that the quality of the seedbed produced by the various types of implement varied significantly in terms of aggregate size distribution, working depth, evenness of the working depth, and straw residue incorporation. However, seed emergence did not correlate with the seedbed quality produced by the implements due to the high soil moisture content and the fact that the combined seed and fertilizer drill used in the experiment did some of the seedbed preparation that the tillage implements did not do.

INTRODUCTION

Soil erosion caused by run off from autumn-ploughed areas is assumed to be one of the major contributors to water pollution in Norway (1). Therefore, successful soil tillage and sowing in spring without any previous tillage operations in autumn is needed if grain production is to survive in the future.

There are several problems to overcome when ploughing is not used as primary tillage. Straw has to be removed or incorporated into the soil to prevent blocking of soil tillage implements and seed drill. However, research has clearly shown that straw in the top layer causes an increase of organic matter which improves the soil structure (2). Improved soil structure is important both for trafficability of the soil and for resistance against soil erosion. The straw residues should therefore be left on the soil surface, and not be burned or removed.

When autumn ploughing is practiced, it is well-known that the topsoil layer dries out more easily in the spring than it does if it is not ploughed. This may cause several problems for ploughless tillage practice. Firstly, the tillage has to be done on wetter soil, which can make it difficult to obtain soil aggregates suitable for seed emergence. Secondly, traffic on wet soil can lead to soil compaction problems. Therefore, the tillage operations should be as few as possible and the load carried by the tractors should be as low as possible. As a result of this, soil tillage implements should require low draught forces to minimize the tractor weight required, and the seedbed should be prepared with a minimum of operations.

MATERIAL AND METHODS

The three field experiments preformed in 1993 were located in the Ås area, S-E Norway. The experiments were designed with three blocks where a block consisted of one replication of each of the seven implement treatments included in the experiments. One experiment therefore consisted of 63 field plots, and the plots were 50m long and 3m wide. The implements used in the experiments are listed in Table 1. Since the combined tine/disc-cultivator was not available for all of the experiments, one of the experiments included only six implements.

The tractor used in the experiments, a MF 399 4WD, was equipped with force transducers (3) with strain gauges in the lower links and strain gauges in the top link to sense the forces between the implement and the tractor. The signals from a potentiometer connected to the upper link to sense link angle were recorded as were the signals from the strain gauges. A dynamometer was attached to the tractor PTO shaft to sense the PTO power transferred to the PTO-driven implements. All the signals were recorded on a digital datalogger at a frequency of 5 Hz, to be analysed later by a computer.

Table 1 Types of implement with some of their characteristics.

Implement	Specifications	No. of tools	Weight, kg	Working width, m
Disc harrow and packer	2 rows with individually mounted discs, and a following packer	24 discs	1165	3
Disc harrow and crumble roller	2 rows with individually mounted discs, and a following crumbler roller	24 discs	1065	3
Dynadrive	2 rotors, one ground driven, which also drives the second	160 tines	1320	2.6
Tine cultivator	3 rows of tines	12 tines	540	3
Combined cultivator	1 row of tines, 1 row of discs, packer	4 tines, 12 discs		3
Rotary cultivator	PTO-driven, vertically rotated brades	88 blades	1415	3
Rotary harrow	PTO-driven, horizontally rotated blades	12 rotors, each with 2 blades	1365	3

Before the soil tillage operations, the weight of straw residue on the experimental fields were determined by sucking the residues from a 2.25m² area of the ground into a basket, from where the dry weight and length characteristics of the straw pieces were determined. Soil strength was determined with the use of vane shear apparatus. Soil cores were sampled to determine moisture content, density, and porosity. The measurements were replicated five times in each of the three fields.

After the tillage operations, working depths were measured (10 replications per plot). Samples were collected for determining aggregate size distribution in the laboratory by sieving the samples (five replications per plot).

The ability of the implements to incorporate straw into the soil was determined by placing a wire with 100 evenly spaced red marks on it onto the tilled soil (4). The number of red marks crossed by straw stems was used as the percentage of straw coverage of the soil surface. Digital photos were also taken with a Canon ION 560 camera for later analysis with the use of a computer program (5, 6). Pictures were also taken with a normal camera for analysis of the coverage with the use of transparencies with randomly placed dots (4).

Seed emergence and seed depth were measured 14 days after sowing.

RESULTS AND DISCUSSIONS

Field characterisation

Table 2 gives some information on straw residue yields, and a characterisation of the straw, where the group «short straws» were the part of the residue which came through slots of 50mm in a sieving appartus, «medium straws» came through slots of 100mm, and «long straws» came through slots of 150mm. On two of the fields (Dyster and Solberg) there were straw residues of winter wheat, which were also cut after the combining operation with the use of a stubble cutter. On the field Østensjø there was straw residue of oil rape seed.

Table 2 Straw residue yield and characterisation of the straw material.

Field	Straw yield kg/ha	Characterisation, % of straw length short	medium	long
Dyster	3210	68	23	9
Solberg	4100	66	21	13
Østensjø	1050	67	17	16

Information on soil types, densities, porosities, water contents, and shear stresses from the fields are given in Table 3. Although there were some variations of soil types, there were only minor differences between the fields in the other parameters. The high water contents in the top layer of the soil clearly indicate that the soil tillage was done under very wet conditions.

Table 3 Soil type, density, porosity, water content, and shear stress.

Field	Soil type	Density kg/l	Pore volume, %	Water content, vol. %	Shear stress, Nm
Dyster	silty clay	1.29	51.2	40.2	41
Solberg	silty clay loam	1.38	48.0	36.0	44
Østensjø	silty clay	1.37	48.3	38.6	42

Power and energy consumption, and working depths

Since the differences in the measured parameters between the experimental fields were not significant, and there was no interaction between implements and experimental fields, only the mean values of all the experimental fields will be discussed here (Table 4). A very low draught requirement was found for the disc harrow with roller packer on the field Dyster. This was due to wrong adjustment of the harrow, which caused the harrow to walk sideways so that the last row of discs ran in the first row's furrows. Therefore these measurements will not be taken into account when the implements are discussed. The PTO-driven rotary harrow and the Dynadrive had significantly higher ($p>0.05$) power consumption than had the others. The rotary cultivator had the low power consumption, due to the negative draught force, corresponding to an average power consumption of -1.8kW/m (included in table 4). When we compare the disc harrow (with the two different types of rollers) with the tine cultivator and the combined cultivator, we can see from the table that the disc harrow required less power that did the tine cultivator and the combined cultivator. The difference in power consumption of the disc harrow with the packer and the crumble roller could be explained by differences in working depths.

Table 4 Calculated power consumption, energy consumption, and working depths of the various types of implement.

Implement	Power consumption kW/m working width	Energy consumption kJ/ha	Working depth mm
Disc harrow and packer	7.1	23588	87
Disc harrow and crumble roller	5.2	17487	79
Dynadrive	11.4	38120	92
Tine cultivator	8.0	26703	95
Combined cultivator	9.2	30493	98
Rotary cultivator	5.2	17299	80
Rotary harrow	10.8	36050	63

The energy consumption of the Dynadrive and the rotary harrow was significantly higher than the energy consumption of the other implements ($p>0.05$). The high energy consumption of the rotary harrow could be explained by a low travel speed and a high power consumption, while the high energy consumption with the Dynadrive could be explained by the high draught alone. The rotary cultivator required the lowest energy consumption, but this was not significantly different from the energy consumption of the disc harrow, the tine cultivator or the combined cultivator. The low energy consumption of the rotary cultivator could be explained by the low power consumption caused by a negative draught.

A comparison of the working depths of the various types of implement shows significant differences ($p>0.05$). The greatest working depths were obtained with the Dynadrive, the combined cultivator, and the tine cultivator, and within this group of implements the differences were not significant, while there were significant differences between this group of implements and the other implements. The difference between the rotary harrow and the other implements was also significant ($p<0.05$).

Power consumption related to working depths and aggregate sizes.
Power consumption per m^2 tilled soil and mean weight diameter of the soil aggregates of the various types of implement are given in Figure 1.

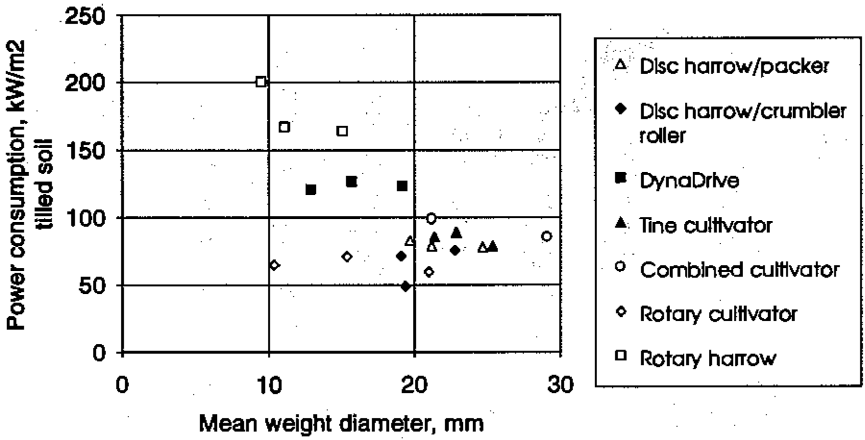

Figure 1 Power consumption of the various types of implements versus aggregate size as mean weight diameter.

Because of very big variations between the replications of the sieving of the samples, no significant differences were found between the implements in terms of mean weight diameter of the soil aggregates. However, the figures indicate that there is a tendency for the PTO-driven implements and the Dynadrive to give smaller aggregates. This was also observed in the field. The high power consumption of the Dynadrive and the rotary harrow was very much due to clod crumbling, while the rotary cultivator used the power best in terms of clod crumbling effectiveness.

Straw incorporation
Figure 2 gives the results of the straw residue measurements, and the figure shows an average of the various types of measuring technique used in the experiments. Since there were big differences in the dry matter yields of straw between the experimental fields, the straw covering percentages in the experimental fields were also different. The differences between the various types of implement were therefore observed on the fields with high straw yields. The results from these fields indicate that the PTO-driven implements incorporated less straw than did the other implements. The differences between the fields Dyster and Solberg could be explained by fewer of the longer pieces of straws in the Dyster field.

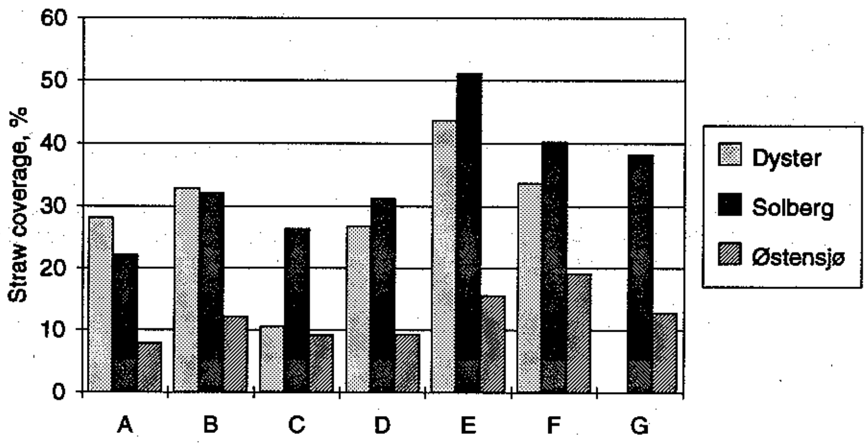

Figure 2 Percentage of straw coverage after soil tillage with various types of implement on the experimental fields. A=Dynadrive, B=tine cultivator, C=disc harrow with packer, D=disc harrow with crumble roller, E=rotary cultivator, F=rotary harrow, G=combined cultivator.

Crop emergence

No significant differences in crop emergence were found between the various test plots. One reason for this is because the combined drill broke up the larger soil aggregates and so improved the tilth of the poorly tilled plots. This effect of the combined drill could be clearly observed however it was not measured. The other reason is that at the time of sowing the soil was very moist so the seeds recieved enough moisture even without the presence of a fine tilth. In the Solberg field it was necessary to drill the seed at a very shallow depth in order to avoid drilling problems caused by the straw residue. Although much seed was left on the soil surface, the high soil moisture content enabled the germination in this field to be as good as in the others. Measured sowing depths are given in Table 5.

Table 5 Sowing depths.

Implement	Sowing depths, mm		
	Dyster	Solberg	Østensjø
Disc harrow and packer	23	21	18
Disc harrow and crumble roller	21	17	20
Dynadrive	19	17	20
Tine cultivator	21	16	21
Combined cultivator	-	17	19
Rotary cultivator	23	18	21
Rotary harrow	20	14	18

CONCLUSION

The experimental results demonstrate significant differences in the power requirements, energy consumption and tillage quality of the various implements tested. Similar differences have been reported elsewhere (7). The disc harrows and rotary cultivators had the lowest power consumption whereas the dynadrive and the PTO powered implements produced the finest tilth. The dynadrive and disc harrows were most effective at incorporating the straw.

Despite the differences in tilth quality and straw incorporation, no significant differences in crop emergence were found. This is probably because of the tillage performed by the combined drill and the high moisture content of the soil.

Under Norwegian conditions the soil moisture content usually drops rapidly around the time of sowing. The results of this experiment and comparison with the emergence of the crops in surrounding fields indicates that it is more important to sow at the correct time, before the soil became dry, than it is to create an optimum seed bed tilth.

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CRUMBLING EFFICIENCY OF VARIOUS IMPLEMENTS

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ABSTRACT

Soil tillage is regarded as a fragmentation process and energy efficiency is investigated for various soil conditions, soil states and implements. The implements comprised some concepts of drags and harrows, twin rotor, gyrospike and rotaspike. The ratio between specific increased surface area and specific supplied energy is termed the crumbling effectiveness parameter, *f*. Having a workable soil state, *f* was almost constant with increasing energy supply. At a loosened and firm soil state, however, *f* decreased with increasing energy supply. Using *f*, implements energy efficiency was compared. Between the implements there was only small differences in efficiency. The most significant difference appeared in loosened soil where implements with high velocity tools had a higher efficiency than those with low velocity tools.

INTRODUCTION

The task of the implement is to fragment the soil to quite fine aggregates. Summing up a lot of experiments, the conclusion is that a good seedbed for cereals should have about 50 % of the aggregates by weight in the range of 0.5-6.0 mm diameter. From a tilling point of view the task is to obtain as energy effective fragmentation as possible. According to the Griffith theory of fracture, there is a relationship between the specific energy absorbed (E/kg) in crushing and the specific increase in the surface area (ΔA/kg). The ratio ΔA/E is an expression of the efficiency of the fragmentation process. Von Rittinger(1) found this relationship to be linear for some brittle materials. Hadas and Wolf, (2,3), showed how the area increase could be calculated. Clods taken from the experimental field and subjected to the drop-shatter test showed a curved relationship between the applied kinetic energy E, and the surface area increase ΔA. The ratio, ΔA/E, did accordingly decrease with increasing energy supply. They further introduced an energy efficiency parameter,

$$\eta = \frac{E}{W}$$

, where E is the energy requirement for fragmentation by the drop-shatter method and W the implement input energy to the soil. The energy efficiency of different implements was, however, poor. Further implement investigations by Wolf and Hadas(4) showed no correlation between the

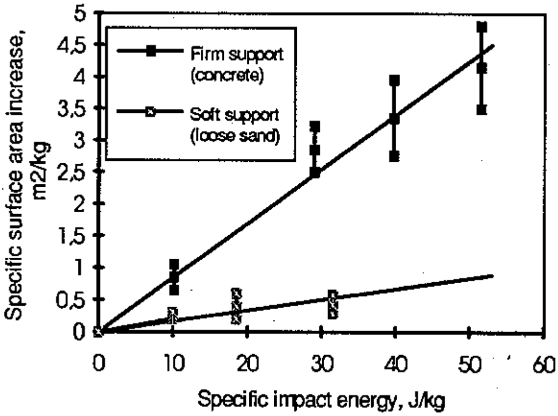

Fig1. The increase in the soil specific surface area, ΔA, in relation to the specific impact energy.

energy input and soil fragmentation. The soil was characterized as dry and clod forming. Investigations with soil specimens is also conducted by Soucek et al.(5) and Bateman et al.(6). Both found clear relationship between applied energy and the resultant fragmentation. Low loading velocities did increase the energy efficiency of the fragmentation process.

Berntsen and Berre(7) performed drop tests where weights were dropped on soil specimens placed on a firm and soft support. The firm support was a concrete floor and the soft support loose sand. A linear relationship was found between the applied specific kinetic energy and the resulting increase in specific surface area, The ratio ,$\Delta A/E$, was called the crumbling effectiveness parameter, *f*. This parameter was constant both for the firm and soft support, but the value of the parameter did, however, depend upon the firmness of the support, see Fig. 1.

This paper presents the effects of the most significant variables influencing fragmentation of soil. Problems adressed to the comparisons of implement fragmentation is highlighted, and comparisons by means of the crumbling parameter, *f*, are discussed. Differences in the crumbling efficiency of some implements are pointed out.

THE IMPLEMENT INVESTIGATIONS

Seedbed preparation was performed on four different sites. At one of the sites there was a heavy soil with 45% clay. Two sites comprised loamy soils with 27 and 24 % clay , and the last site a sandy soil with 15% clay. The experiments were conducted over a period of 5 years. Over the years soil conditions varied considerably. Seedbed preparation was performed in the spring. In four of these years the soil was ploughed in the autumn, and one year it was left unploughed. In some of the years a loosening operation in the spring was performed prior to seedbed preparation. The loosening was either carried out by ploughing or chiseling just before seedbed preparation. This loosened soil was classified as the loosened soil state. In addition seedbed preparation was performed on soil states judged as workable soil and firm soil. Loosened soil corresponds to the remoulded state and workable and firm soil to the cemented state in the definition of Hettiaratchi (8). On all sites cereals had been grown in the previous years.

The implements used were grouped as, drags, harrows, progressive cultivators, twin rotor cultivator, gyrospike and rotaspike. Gyrospike and rotaspike were the only p.t.o. driven implements. The progressive cultivator embodied a special concept, chisel tines broke up the soil in stages. The first row of tines broke up the soil down to about 1 cm depth, the second row to 2.5 cm depth and the third row to about 4 cm depth. The chisel tines were equipped with 30 cm broad duckfoot shares. Within the rows the shares where placed very close together, and in the driving direction the shares were placed behind each other.

Except for one investigation the implements passed only once over the same plot. In the exception experiment the implements passed 5 times over the same plot. This soil consisted of a loosened dry loam, a workable dry loam, a firm dry loam and moist workable clay. The loam soil crumbled easily.

On a few fields drop tests were conducted during the implement investigations. These tests were, however, very labour consuming. Only two levels of specific impact energy, therefore were applied to the soil specimens.

RESULTS AND DISCUSSION

Effect of soil state and soil conditions

Averaging over implements and sites, the specific surface area increased with supplied specific energy dependant upon soil state and moisture content ($P < 0.01$). Irrespective of the soil state, increased moisture content reduced the increase in specific surface area, presumably due to deformation of soil instead of fragmentation. The increase in specific surface area was found largest for workable soil and smallest for loosened soil ($P < 0.01$), see Fig. 2. The low increase of specific surface area for loosened soil fits with the case in the initial drop test, Fig.1, where the clods were supported by loose sand. Instead of fracturing the clods, the tools of the implement push the clods aside. The difference between workable and firm soil probably reflects the difference in strength of the two soil states. Bateman(6) found that increased density increased the energy requirement of fragmentation.

The difference in soil conditions between autumn ploughed and unploughed soil had no significant influence on the increase in specific surface area, supplied energy or crumbling effectiveness.

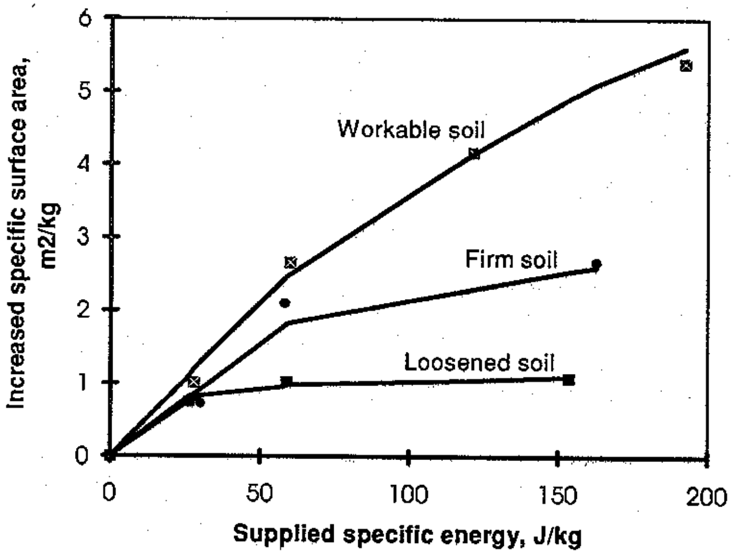

Fig.2. Relationship between specific increased surface area and supplied specific energy of implements on the three soil states. The implements passed once over the same plot.

The drop test concept and implement investigations

Statistical analysis showed that supplied specific energy was the most significant variable influencing the increase in specific surface area ($P < 0.01$). According to the initial drop test, see Fig. 1, a linear relationship between specific increased surface area and supplied specific energy was expected. Fig. 2 shows a almost linear relationship between these quantities for the workable soil and a non-linear relationship for the loosened and firm soil. This means almost constant crumbling effectiveness, f, for workable soil, and decreasing effectiveness with increasing specific energy supply for loosened and firm soil. Refering to the drop test this behaviour might seem unexpected. However, the supplied specific energy range was larger in the implement investigations than in the drop test.

In the separate experiment where the implements passed five times over the same plots three implements; a harrow, a progressive cultivator and a twin rotor were used. In the cases where the implement in the first pass attacked unloosened soil, this pass should correspond to drop test fragmentation on firm support, and the next passes to fragmentation on soft support. Figure 3 shows the influence of supplied specific energy.

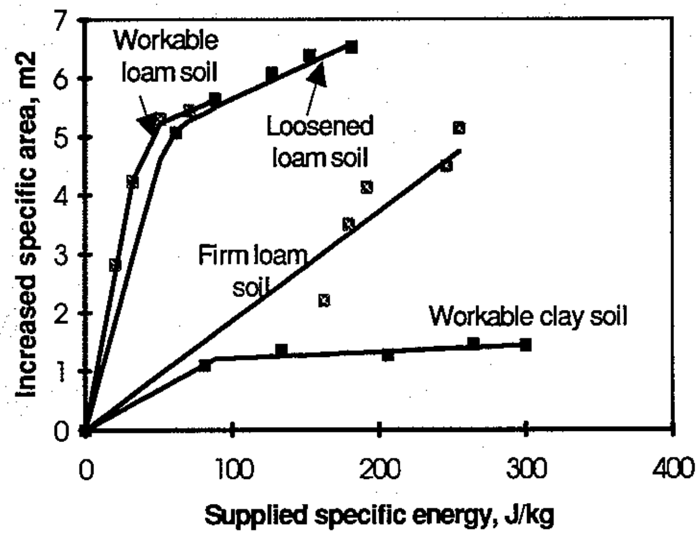

Fig.3. Relationship between increased specific surface area and supplied specific energy in the experiment where the implements passed over the same plots 5 times.

The result for workable clay soil and for loosened loam soil confirmed the behavior expected from the drop test. The first pass caused a very high increase in specific surface area in relation to input energy. For the remaining 4 passes the increase was quite small. Consequently many clods were crushed during the first pass, and only few in later passes. An explanation of this behaviour may be that the first pass completely loosened the soil and/or crushed the most brittle clods. Accordingly the workable loam soil required three implement operations and the firm soil at least five implement operations to completely loosen the soil and/or to crush the most brittle clods. Measurements of the strength of the clods showed the highest clod strength in workable clay and approximately the same clod strength of workable and firm loam. The effect of the clod strength therefore explains the behaviour of workable clay, but not the different behaviour of workable and firm loam. One could then expect that the firm soil needed more implement operations to get completely loosened. Watching the soil loosening in the field does not, however, support such an explanation.

Effect of implements and tools

In addition to the effect of specific supplied energy there was an independent implement effect and an interaction between implement and soil state ($P < 0.01$). On loosened soil the implement equipped with low velocity tools such as drags, harrows and progressive cultivators yielded significant poorer increase in specific surface area then did implement with high velocity tools such as the twin rotor, gyrospike and rotaspike, see Fig.4 . On workable and firm soil this difference was, however, not significant. Inevitably fragmentation of clods in loosened soil requires the implements with high velocity tools, otherwise the clods will be pushed aside.

The crumbling effectiveness parameter, f, was also significant greatest for the high velocity tools on loosened soil. On workable and firm soil there was no significant velocity effect of the tools. This means that the great increase in surface area of the gyrospike was a result of the high energy input.

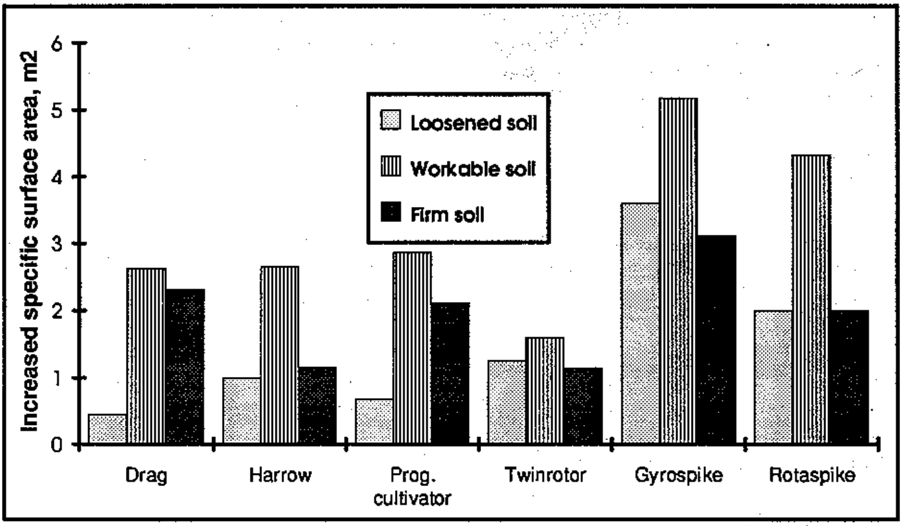

Fig. 4. Increased specific surface area of the implements on the different soil states

Some implements are equipped with rollers which are assumed to give good crumbling. A special experiment therefore comprised rollers of different weights and designs and a dragbeam. The weights of the rollers were 100, 200, and 300 kg/m. The heaviest one was a Cambridge roller. The heaviest roller produced the greatest increase in specific surface area. However, the specific crumbling effectiveness was not influenced.

In the experiment where the implements passed five times over the same plot, the specific energy input increased with the number of passes. The draught force was, however, fairly constant. Loosening of the soil consequently, had little effect on the required draugth.

As a basis for a quantification of the energy efficiency of implements, Hadas and Wolf (2,3) performed drop-shatter tests simultaneously to the implement investigations. The drop-shatter energy of fragmentation, E, was related to the implement input energy to the soil, W, yielding the parameter; $\eta = \frac{E}{W}$. The drop-shatter method was assumed to be very energy efficient. In our investigations drop tests with falling weights were carried out in some sites simultaneously to the implement investigations to obtain η. The fragmentation obtained with the drop tests was, however, often poor. The outer part of the soil specimens could be fragmented while the core was compressed implying that some impact energy was compacting instead of fragmenting the soil. This incomplete fragmentation was a recurrent phenomenon at the prevailing field moisture content. Different designs of the falling weight and the support did not bring any solution to this experimental problem. Accordingly we terminated our efforts to evaluate η.

CONCLUSIONS

The specific surface area increase depended upon soil state and moisture content. Classifying soil states as loosened, workable and firm, the workable state gave the highest and the loosened soil the lowest increase in specific surface area. Irrespective of soil state, increased moisture content reduced the increase in specific surface area. Supplied specific energy was the most significant variable influencing the increase in specific surface area. Workable soil showed an approximate constant ratio between increased specific surface area and supplied specific energy. At the loosened and firm state this ratio decreased with increasing energy supply.

Comparisons of implements energy efficiency should be carried out at the workable soil state. The crumbling effectiveness parametre, f, then serves as a proper expression for such comparisons.Otherwise comparisons should be conducted at the same specific energy supply to the soil.

Implements with high velocity tools yielded the highest crumbling effectiveness at the loosened soil state. At the workable and firm states there was no difference in effectiveness between high and low velocity tools. Rollers and dragbeam showed almost the same effectiveness for different supplies of energy.

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THE ENERGY EFFICIENCY OF SEEDBED PRODUCTION FOLLOWING MOULDBOARD PLOUGHING

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ABSTRACT

Field experiments were conducted for a period of four years from 1987 to determine the efficiency with which a range of cultivation implements could produce a seedbed for combinable crops following mouldboard ploughing. Laboratory experiments were also conducted on samples of the field soils and measures of both field and laboratory produced tilths and energy requirements were compared. Results indicated that less aggressive implements were often capable of producing seedbeds equal in quality to those of powered machines but with less input of energy and labour despite requiring more passes across the land. Yield was generally unaffected by tillage treatment. Cutting of soil aggregates in laboratory tests suggested that significant improvements to field machines could be made.

INTRODUCTION

During experiments conducted in the 1970's at the Institute, when a range of both primary and secondary cultivation systems were compared[1], it was evident that considerable savings in energy, labour and cost could be made by reducing the number and intensity of cultivations with little effect on cereal crop yield. These savings were mostly achieved with existing machines used either less frequently or at a shallower depth of operation. During this and subsequent work, it was evident that there was considerable potential for improving the efficiency with which secondary cultivation implements reduced soil aggregate size. This was considered to be of particular importance on clay soils following mouldboard ploughing. In the study described here, the aim was to compare the relative efficiencies of different mechanisms in terms of the labour and specific energy needed to produce a seedbed following mouldboard ploughing. These data would be compared with those derived in the laboratory using impact and cutting techniques to break soil aggregates.

MATERIALS AND METHODS

Implements and sites

Five implement types were used throughout the experiment to create a seedbed following mouldboard ploughing, for a rotation of combinable crops. In the first year of the experiment, four sites each having three replications of each treatment were set up on soils ranging from clay to sandy clay loam. Individual plots were 36 m long and, depending on the width of the implement, approximately 6 m wide. Subsequently, and to allow more detailed investigations, the sites were reduced to two. Table 1 provides details of the sites and the cultivators used in each year of the experiment. On the clay sites, the soil was rolled immediately after ploughing to level the surface and minimise moisture loss.

Table 1 Details of the soils and implements used on the sites for each year of the experiment

Year	Site name	Soil details				Implements used[2]
		Texture[1]	Particle size distribution			
			Clay	Silt	Sand	
1987/	Sil	Clay	47.3	23.1	29.6	Rh,Sr,Tr,Th,Dh
1988	NP1	Clay	48.4	22.7	28.9	ditto
	NP2	Sclylm	23.9	27.8	48.3	ditto
	NP3	Clylm	35.8	28.9	35.3	ditto
1988/	NP1	Clay	50.7	25.3	24.0	Rh,Sr,Tr,Th,Dh
1989	NP2	Clylm	32.5	28.6	38.9	ditto
1989/	NP1	Clay	50.7	25.3	24.0	Rh,Sr,Tr,Th,Dh,Fr
1990	NP2	Clylm	32.5	28.6	38.9	ditto
1990/	NP1					Rh,Sr,Tr,Th,Dh,Fr
1991	NP2					ditto

1. 'Sclylm' denotes Sandy clay loam and 'Clylm' denotes Clay loam
2. Rh 2.99 m wide rotary harrow with 260 mm long vertical intermeshing contra-rotating tines on radius of 125 mm followed by a packer roll
 Sr 2.89 m wide spiked rotary cultivator with radial pointed bars on 565 mm diameter spaced 60 mm apart on three scrolls followed by a crumble (1987) and thereafter a packer roll (1988 on)
 Tr 2.61 m wide twin intermeshing soil driven 640 mm diameter rotors with 1:3 front to rear ratio and tines at 100 mm centres followed by a crumble roll
 Th Variable widths and designs of tine harrow incorporating either (a) rigid vertical bars spaced at circa 85 mm centres or (b) 4 rows of sprung "S" tines at circa 30 mm spacing. Both designs had an adjustable front levelling board and rear crumble (a) or (b) packer roll
 Dh Tandem and offset disc harrows with 560, 600 and 700 mm diameter discs spaced at between 200, 235 and 305 mm centres and with a mass of 76, 84 and 160 kg/disc (Ta, Of1 and Of2 respectively)
 Fr 3.07 m wide water filled flat roll with a diameter of 785 mm and mass of 2290 kg

Machinery performance

A 75 kW front-wheel-assist tractor, with dualled rear wheels and front adjustably loaded press wheels within the track width, was used for all operations. A fuel flow meter, doppler radar distance meter and wheel speed transducers provided a means of assessing engine power requirements[2](pp 5&6), true ground speed and wheel slip. To measure implement draught a three point linkage dynamometer[3] was connected between the implement and the tractor and a commercial torque and speed transducer was coupled in the power take-off (pto) driveline. Depth of implement operation was recorded by means of a skid fitted with a linear transducer. All these data were transferred using a telemetry link[4] from the tractor/implement combination to a vehicle on the headland. An estimate of the specific energy required by each implement was calculated assuming that the volume of soil moved was proportional to the products of the width, depth and forward speed; the energy was then simply the product of this figure and the power consumed by the implement.

Soil measurements
In the first two years of the trial, soil surface tilths were assessed from photographs of four 0.25 m^2 areas taken at random positions on each plot. These photos were then compared and aligned with photographs of surface tilths which had been assessed by dry sieving to give a single index of aggregate size. This index, the mean area diameter (MAD), was derived from the sum of the product of individual proportions of aggregates of a particular mean size and their mean size. In the two subsequent years a slightly modified analysis was introduced so that comparisons with laboratory produced tilths could be made more easily. This analysis provided the mean weight diameter (MWD) of the tilth and was derived from:

$$MWD = \sum_{i=1}^{n} X_i W_i \tag{1}$$

where X_i is mid size of each sieve interval
W_i is the weight of the aggregates of that size range as a proportion of the total sample weight
and n is the number of size fractions

Laboratory tests commenced in the second year of the experiments and consisted of impact and cutting of aggregates collected from the ploughed soil just prior to secondary cultivation. Due to equipment problems, the impact tests were only conducted in the second and fourth years. Fifteen individual unrestrained aggregates were subjected, while stationary, to impact from a rectangular mass travelling at speeds of between 7 and 19 m/s. Strain gauges and sampling electronics enabled the energy dissipated during impact to be calculated, and the MWD of the soil fragments collected from retardent sheeting was calculated by sieving. The energy required to fail the soil by cutting was obtained by measuring the force needed to push a 30 degree angle cone of 54 mm base diameter through 15 individual aggregates. Eight such pushes were made on eacb aggregate, using the largest fragment on each occasion, and the final MWD of the tilth was calculated by sieving. This procedure was modified in the last two years of the experiment so that the tilth produced by the cutting technique was in line with that produced by the spiked rotary cultivator in the field. To compare the energy needed to produce a tilth using the cutting and impact techniques with implements in the field, some account needed to be taken of the differences in aggregate and soil bulk densities. Bulk density of the top 100 mm of the ploughed layer was therefore established using the technique described by Andersson and Håkansson[5], while aggregate densities were measured using the immersion technique[6]. The energy required in the laboratory was then multiplied by the ratio of the field bulk density to the aggregate density before comparisons were made.

Crop measurements
Crop establishment was determined from ten counts of plants over an area of 0.25 m^2 on each plot. Yield per hectare was calculated from single cuts along the length of each plot with a standard combine harvester having a 3.7 m wide cutting table. Grain from the harvester was unloaded into a trailer standing on weigh pads.

RESULTS AND DISCUSSION

Implement energy and soil tilth
Results from the NP1 site, which were considered to be generally representative, are

summarised in Table 2, but some slightly different trends from the lighter soil sites (NP2 & NP3) are also discussed. In 1987 at both of the clay soil sites (Sil & NP1), the tine harrow (Th) demonstrated the best overall performance, followed closely by the twin rotor (Tr). On the lighter soils, the power driven cultivators were more competitive in terms of tilth and labour requirement, but were higher in energy demand than Tr and Th. The relatively light-weight disc harrow performed least well in terms of tilth and was generally more demanding of labour as well. In 1988, Table 2 shows that the trend on the clay soil was similar to 1987 with the tine harrow and twin rotor providing a finer tilth than the other treatments, and Th having the best overall performance. At the NP2 site there was little to choose between the treatments in terms of tilth, but Th had the best overall work rate while the disc harrow was again at the lower end of the performance scale, despite being heavier.

Table 2 Tillage implement performance and resultant tilth on ploughed soil for each year of the experiment at the NP1 site

	Implement (for key see Table 1)				
Measurement	Rh	Sr	Tr	Th	Dh
1987, mc[1] 25.6%				a, 3.09m	Ta, 2.34m
Energy, kJ/m^3	244	230	38	50[2 passes]	100
Tilth, MAD, mm	42.0	43.9	42.0	34.6	46.0
Labour, h/ha	1.51	1.27	0.56	0.88	1.17
1988, mc 22.9%				b, 3.96m	Of1, 3.05m
Energy, kJ/m^3	131	208	84[2 passes]	68[2 passes]	109[2 passes]
Tilth, MAD, mm	28.3	30.2	24.2	20.4	33.6
Labour, h/ha	0.99	0.96	1.14	0.76	0.99
1989, mc 8.0%				a, 4.17m + rollx3	Of1, 3.07m + rollx3
Energy, kJ/m^3	595[2 passes]	374[2passes]	394[2passes]	445[4 passes]	485[4 passes]
Tilth, MWD, mm	32	44	35	27	32
Labour, h/ha	3.03	2.64	3.97	2.96	3.73
1990, mc 15.7%				b, 2.96m + roll	Of2, 2.83m + roll
Energy, kJ/m^3	138	273[2 passes]	120[2 passes]	110[2 passes]	139[2 passes]
Tilth, MWD, mm	18.6	22.1	23.9	19.2	19.1
Labour, h/ha	0.86	2.88	1.36	1.33	1.51

1 mc is the moisture content at the time of the first pass of the secondary cultivator
a, Ta etc., see Table 1, m is metre width of implement

Soil conditions in 1989 were very dry and labour and energy requirements were significantly higher than in previous years. However, the underlying trend was the same, with the tine harrow producing the best tilth and only a slightly higher labour demand than the spiked rotary cultivator. At the lighter soil site (NP2) the powered cultivators exhibited some advantage in terms of soil tilth (21 mm MWD), but the Th, with a tilth MWD of 25 mm, had the lowest energy and labour requirement. Unlike previous years, the rotary harrow (Rh) exhibited the best overall performance although it was closely followed by the tine harrow. It was also notable that the disc harrow performed rather better than in previous years and this was almost certainly due to the increased weight of harrow, although this would have been offset to some extent by the increased disc spacing. At the NP2 site there was a similar trend, although the twin rotor stood out in terms of its low energy and labour requirements, only lacking in its overall performance by its rather poorer tilth production.

In practical terms all of the implements were easy to operate, but some improvements in their design or method of use were introduced and other refinements could still be made. For example, if surface residues had not been buried deep enough during ploughing, the tine harrow could pull them onto the surface. In moist conditions, the crumble rollers would often fill with soil and although the new design of packer rollers overcame this problem, it was observed that on moist clay soils they often caused some sealing of the surface. In the dry conditions of 1989, when multiple passes of all implements were needed, measurements showed that 75% of the tilth had been produced in the first pass, and the law of diminishing returns was observed to apply. It is considered that performance of the disc harrow could be improved considerably if a firming roll were positioned between the front and rear gangs. This would not only create some additional soil fragmentation, but would provide a surface within which aggregates could not move so easily out of the path of the discs. Other research investigating different settings of the power driven cultivators indicated that more appropriate settings could improve their efficiency considerably. These results will published in an extended version of the present paper.

Laboratory created tilths

Results in Table 3 suggest that implement (Table 2) and cutting energies are only comparable in conditions when the soil is in a friable state, as in 1988 for example. In 1989, when field energy figures were very high, the energy needed to cut the soil remained at a similar level to 1988. Where impact was used to break aggregates, a similar trend was apparent.

Table 3 Impact and cutting energy and soil tilth at NP1

Year	Impact velocity, m/s	Impact energy, kJ/m^3	MWD, mm	Cutting energy, kJ/m^3	MWD, mm
1988	11.7	228	51	80	41
1989	nr	nr	nr	73	26
1990	7	60	53	50	26
	10	120	45		
	14	183	40		
	17	237	35		
	19	318	27		

However, it was also noticeable that at the lower impact speeds (7 - 12 m/s), degree of soil shatter was poor compared with field implements. The spiked rotor for example, operated at a tip speed of 5.6 m/s in 1990, resulted, after two passes, in a tilth with a MWD of 22.1

mm and energy input of 273 kJ/m^3. The nearest equivalent with the impacting tine was 318 kJ/m^3 of energy to produce a tilth of 27 mm MWD. Both the impact energy and the MWD of the resulting aggregates were approximately linearly related to impact speed. Field implements needed between two and six times the energy required by the cone.

Crop responses

Only in one year was there any treatment related significant difference in crop yield. In 1989/90, both the plant numbers and the yield from the Sr plots was significantly lower than from all the other treatments and this was almost certainly due to the coarse tilth which was produced (44mm). Over the term of the experiment, there was an underlying trend for the non-powered cultivators to produce a slightly greater yield than the pto powered machines.

CONCLUSIONS

On heavier soils, pto powered cultivators are less efficient at producing a tilth, in terms of energy and labour requirements, than are some passive cultivators. However, the powered cultivators are normally capable of creating a seedbed in fewer passes across the field. On lighter soils there is little to choose between the efficiencies of powered and non-powered cultivators. The most efficient machine overall was the tine harrow. The most efficient method of creating a tilth in the laboratory was cutting with a cone, this also being a factor of between 2 and 6 times more efficient than field machines. Impacting soil aggregates at up to 19 m/s was less efficient at creating a tilth than existing field machinery.

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PREDICTION OF UNDERCUTTER-SWEEP TILLAGE TOOL DRAUGHT BY MATHEMATICAL MODELLING

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ABSTRACT

Mechanics of equilibrium approach was used in developing equations for the prediction of draught on Undercutter-sweeps. Model tools were designed for the experimental verification of the prediction equation developed.

A backward elimination statistical procedure was employed for providing informations on factors that most significantly influenced draught of undercutter-sweeps. The five factors were tool slide angle, tool nose angle, tool lift height, tool velocity and soil depth.

Results showed that it is possible to predict draught on undercutter sweeps by using soil property and tool parameter values. The prediction model equation predicted lower draught than experimental model equation, particularly at shallow depths. Results further showed that soil depth was the most dorminant single factor in the model equation.

INTRODUCTION

Design of soil cutting tools for agricultural purpose is a complex engineering problem because of the variability of soil conditions and the fact that soil is nonhomogenous and anisotropic. Design of tillage tools is however based on soil homogeneity.

Payne (1956) investigated the relationship between tool geometry, speed of operation and the volume of soil upheaval in front of tillage tools, using soil mechanics theory. Kawamura (1952) studied tools with various angles of inclination and operating at varying speeds and soil depths. He developed a mechanics theory to determine the angle of inclination corresponding to minimum draught. Soehne (1956), Luth and Wismer (1971), and, Wismer and Luth (1972) investigated draught of plane blades at varying angles of inclination in different soils. They concluded that draught was made up of soil and soil-metal frictional components, soil shear failure, acceleration force and soil cutting resistance. They further concluded that for low angles of inclination (less than 40 degrees), the shear surface was a straight line.

McKyes and Ali (1977) applied mechanics of equilibrium theory to develop a mathematical model for calculating draught of inclined blades based on straight line failure plane theory of the soil.

Undercutter-sweep design

In the past, practical knowledge of plane blades was utilized in the fabrication of Undercutter-sweeps but of recent the need to optimize their design to achieve better performance necessitated further theoretical development.

Sirohi (1967) studied the influence of the geometric elements of several sweeps on draught. The parameters studied were slide angle, nose angle, tool width and tool surface area. He found the optimum slide angle to occur between 13 and 15 degrees. This is in close agreement with what was obtained for plane blades (Luth and Wismer, 1971; Soehne, 1956; Wismer and Luth, 1972). Sineokov (1965) pioneered the development of design parameters for cultivator-sweeps for use in soil loosening and in the removal of weed plants by means of undercutting. Design parameters selected were as defined by Sirohi (1967).

Mathematical Modelling

Knowledge of soil mechanics had been previously applied by many authors (Osman, 1974; Payne, 1956; Sirohi, 1967; Soehne, 1956) to soil-machine studies. Due to wide variability that can result from the use of natural soils, artificial soils have been successfully employed for tillage and traction studies (Clark and Liljedahl, 1968; Shrock, 1977). Clark and Huziyyain (1972) showed that vector mechanics can be used to predict forces on soil segments and tillage tools respectively.

If a soil segment is assumed to slide parallel to the direction of tillage tool travel, along the tool's slide angle , as shown in Figures 2 and 3, then the force components on the tool are:

Horizontal force component:

$$F_X = \frac{N_O}{(1 + \tan^2\gamma + \cot^2\theta)^{1/2}} + \mu' N_O\cos\theta\, kb\cos\gamma \qquad (i)$$

Side force component:

$$S = \frac{N_O\cot\theta}{(1 + \tan^2\gamma + \cot^2\theta)^{1/2}} + kb\sin\gamma \qquad (ii)$$

Vertical force component:

$$V = \frac{N_O\cot\theta}{(1 + \tan^2\gamma + \cot^2\theta)^{1/2}} - \mu' N_O\sin\theta \qquad (iii)$$

similarly, the force components on the soil segment are:

Horizontal force component:

$$F_X = \frac{N_1}{(1 \tan^2\gamma + \cot^2\psi)^{½}} + B\cos\psi + \mu N_1\cos\psi + cA\cos\psi \qquad (iv)$$

Side force component:

$$S = \frac{N_1\tan\gamma}{(1 + \tan^2\gamma + \cot^2\psi)^{½}} + kb\sin\gamma \qquad (v)$$

Vertical force component:

$$V = G + B\sin\psi + \mu N_1\sin\psi + cA\sin\psi - \frac{N_1\cot\psi}{(1 + \tan^2\gamma + \cot^2\gamma)^{½}} \qquad (vi)$$

From the above equations, the cutting resistance components (kbsinγ and kbcosγ), and, the normal force on the tool (No) and that on the soil failure surface (N_1) can be substituted for. The resulting horizontal draught is given as

Horizontal draught force,

$$F_X = \frac{2}{Z}\left[G + (B+cA)\cos\psi\,[\tan\psi - R+Q]\right] \qquad (vii)$$

where:

$$Z = \frac{Cot\theta - \mu'\sin\theta\,(1 + \tan^2\gamma + \cot^2\theta)^{½}}{\mu'\cos\theta(1 + \tan^2\gamma + \cot^2\theta)^{½}} + Q - R$$

$$Q = \frac{Cot\psi - \mu'\sin\psi(1 + \tan^2\gamma + \cot^2\theta)^{½}}{\mu'\cos\theta(1 + \mu\cos\psi)\,(1 + \tan^2\gamma + \cot^2\psi)^{½}}$$

$$R = \frac{Cot\theta - \mu'\sin\psi(1 + \tan^2\gamma + \cot^2\theta)^{½}}{\mu'\cos\theta(1 + \cos\psi)(1 + \tan^2\gamma + \cot^2\psi)^{½}(1 + \tan^2\gamma + \cot^2\theta)^{½}}$$

The approach described by Soehne (1956) was used in obtaining expressions for the weight of soil segment (G) and the acceleration force on the soil segment (B) respectively.

Draught Prediction

The five factors under study were used to design twenty-nine model tools. A central composite statistical design was employed for the investigation as shown in Table 1. Information from Table 1 and calculations for the various surface areas of the tool were utilized in draught prediction using the draught equation developed above. This was achieved through the aid of a Digital Equipment Corporation Minicomputer.

Table 1. Design parameters for model undercutters

Parameter	Levels				
	-2	-1	0	+1	+2
Slide angle, θ (^{o})	10	15	20	25	30
Nose angle, 2γ (^{o})	62.5	75	87.5	100	112.5
Lift height, H (cm)	1.66	2.30	2.96	3.58	4.22
Soil depth, D (cm)	1.27	2.54	3.81	5.08	6.35
Speed, V (m/sec)	0.83	0.97	1.11	1.25	1.39

Experimental procedure

A laboratory soil bin with artificial soil as described by Shrock (1977) was used for this investigation. The test tool dynamometer consisted of an outer and an inner (inverted - T) frame between which were mounted six load cells and their flexures. These load cells were capable of measuring the horizontal, vertical and side force components and their moments.

Soil Preparation and Testing Procedure

It was necessary to process the artificial soil used in the soil bin to provide minimum variation in soil density with depth as required by the prediction equations. This was achieved by rototilling the soil, levelling it with a levelling blade and using three roller passes to compact the soil for each preparation. Soil strength properties were determined by the direct shear test and the Cohron shear graph methods respectively while the soil-metal interface property was determined on the surface of prepared soil using a 232 square centimetre plate of cold-rolled steel, the same material used for fabricating the model tools. The strength distribution in the soil profile was periodically checked using a hand held cone penetrometer.

Model tool testing procedure

Draught on each model tool was monitored by using a SYMM-1 microprocessor manufactured by Synertek Systems Corporation in conjunction with a multi-channel recorder with signal conditioning. Only six channels were utilized on the recorder. The microprocessor was programmed to sample 20 data points per second for five seconds. The test length of the bin was five meters. One test run was made for each soil preparation and each test was replicated. Prior to each test run, a hole was dug and the model tool lowered to the required depth. The flow rate of the previously calibrated hydraulic motor was selected for the required speed. Data generated for each test run were stored on a cassette tape. This data was latter transfered into the minicomputer for subsequent data reduction.

RESULTS AND DISCUSSION

The average soil density value was determined. This value was used for the determination of soil strength properties. The resulting soil cohesion and angle of soil shearing resistance were 6.60 kPa and 26.86 degrees respectively. The angle of soil-metal friction as determined on the prepared soil surface was 24 degrees. It was observed that soil failure pattern depended, to a large extent, on the depth of operation and tool geometry and was little influenced by the range of velocities used. The bulldozing effect of some of the model tools at shallow depths accounted for the unreasonably high draught for these tools. A statistical model building technique that would provide information on the influence of each of the five factors on draught was employed. This technique which estimated the first, second and third order interactions was thought best and was achieved through the statistical package (SAS 79). A backward elimination procedure was employed for the analysis of the data resulting from the analytical (prediction) equation and the experimental investigation. The resulting (statistically built) model equations are presented below. That from the experimental data was referred to as Experimental Model, Draught or just as "Draught" while that from the prediction equation data was referred to as Predicted Draught or just "Pdraught"

$$\begin{aligned}\text{Draught} = {} & 82.946 + 21.622D - 1.524H\theta + 2.018H\gamma + 0.364D\theta - 0.227D\gamma \\ & + 0.269\theta\gamma + 0.001V^2 - 0.262\gamma^2 + 0.935H^3 + 0.004\gamma^3 + 2.554HD^2 \\ & - 2.647H^2D + 0.019H^2V - 0.004\theta\gamma^2 - 0.266H^2\gamma\end{aligned}$$

R^2 value = 0.96774.

$$\begin{aligned}\text{Pdraught} = {} & 59.384 + 95.970H + 73.058D - 9.227\gamma - 21.691HD - 0.078H \\ & - 0.185H\theta + 0.045DV + 0.987D\theta - 0.648D\gamma + 0.010V\theta - 0.002V\gamma \\ & - 0.314\theta\gamma - 15.404H^2 + 0.219\theta^2 + 0.213\gamma^2 - 0.002\theta^3 - 0.002\gamma^3 \\ & + 0.206HD^2 - 3.714H^2D + 0.013H^2V + 0.004\theta\gamma^2\end{aligned}$$

R^2 value = 0.99966

The above equations were used to generate data needed for plotting the influence of any combination of these factors on draught.

Effects of soil depth on draught

In both cases, increasing depth of tool operation brought about an increase in draught for given levels of tool lift height, slide angle and nose angle. The range of velocity used was 75-80 m/sec. This increase in draught was due to increase in the force needed to accelerate and lift the soil segment. Depth was the most dorminant single factor in the equations (Figure 4).

Effects of tool slide angle on draught

For given levels of other factors, increasing the tool slide angle increased draught. This was mainly due to increase in the acceleration and frictional forces on the soil segment (Figure 4).

Effects of tool velocity on draught

Velocity entered into the two equations by interacting with other factors and as a square term. Except at shallow depths where the influence of speed was not appreciable, an increase in tool velocity increased the draught. This was because an increase in tool velocity brought about an increase in the force needed to accelerate the sheared soil segment as shown in Figure 4.

Effects of tool nose angle on draught

The contribution of nose angle to the equations was in the form of interactions with other factors. Results showed a decrease in draught as nose angle was increased up to 100 degrees. The decrease was due to a decrease in the acceleration force and the weight of soil segment as the tool nose angle was increased.

Effects of tool lift height on draught

Results showed an increase in draught as the tool lift height was increased as a result of an increase in the force needed to lift and accelerate the soil segment. Beyond a lift height of 3 cm which translates to about 12 cm for prototype tools, there was a poorer agreement between the experimental draught and the predicted draught.

CONCLUSION

1. The results of this investigation showed that it is possible to predict draught on undercutters using prediction equation based on the equilibrium of soil forces on the surface of the tool.

2. Predicted draught was lower than experimental draught for some model tools, particularly at shallow depths due to limitations imposed on the design of the tools and problems of preparing the soil for the tests.

3. Minimum draught was observed for a nose angle of 100 degrees

4. Soil depth was the most dorminant single factor in the equations.

5. Beyond a lift height of 3cm there was a poorer agreement between the predicted draught and the experimental draught.

LIST OF SYMBOLS

N_0 normal force on the tool blades

N_1 normal force on soil failure surface

k soil cutting resistance

b length of the cutting edge of the tool blade

μ' coefficient of soil metal friction

μ coefficient of soil shearing resistance

θ tool slide angle in the direction of travel

2γ tool nose angle

β angle of inclination of tool wing to the horizontal plane

ψ angle of soil forward failure surface

c soil cohesion

B acceleration force on the soil segment

A area of soil forward failure surface

G weight of soil segment

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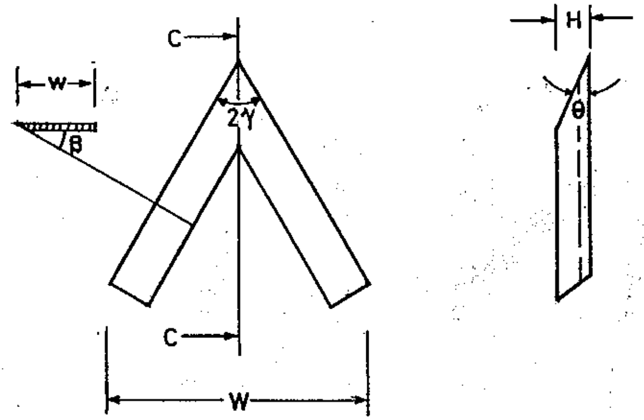

a) PLAN VIEW b) SECTION C-C

Fig.1. Geometric element of an Undercutter-sweep

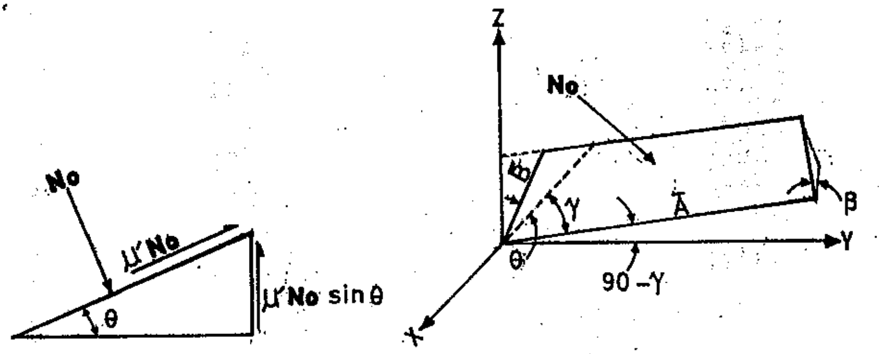

Fig.2. Forces acting on the tool

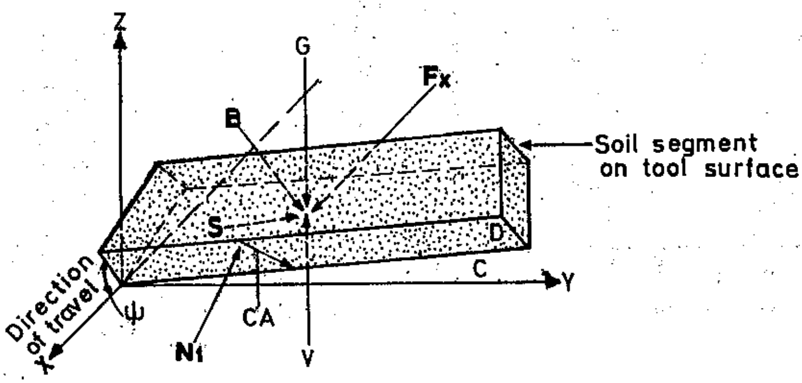

Fig.3. Forces acting on the soil segment

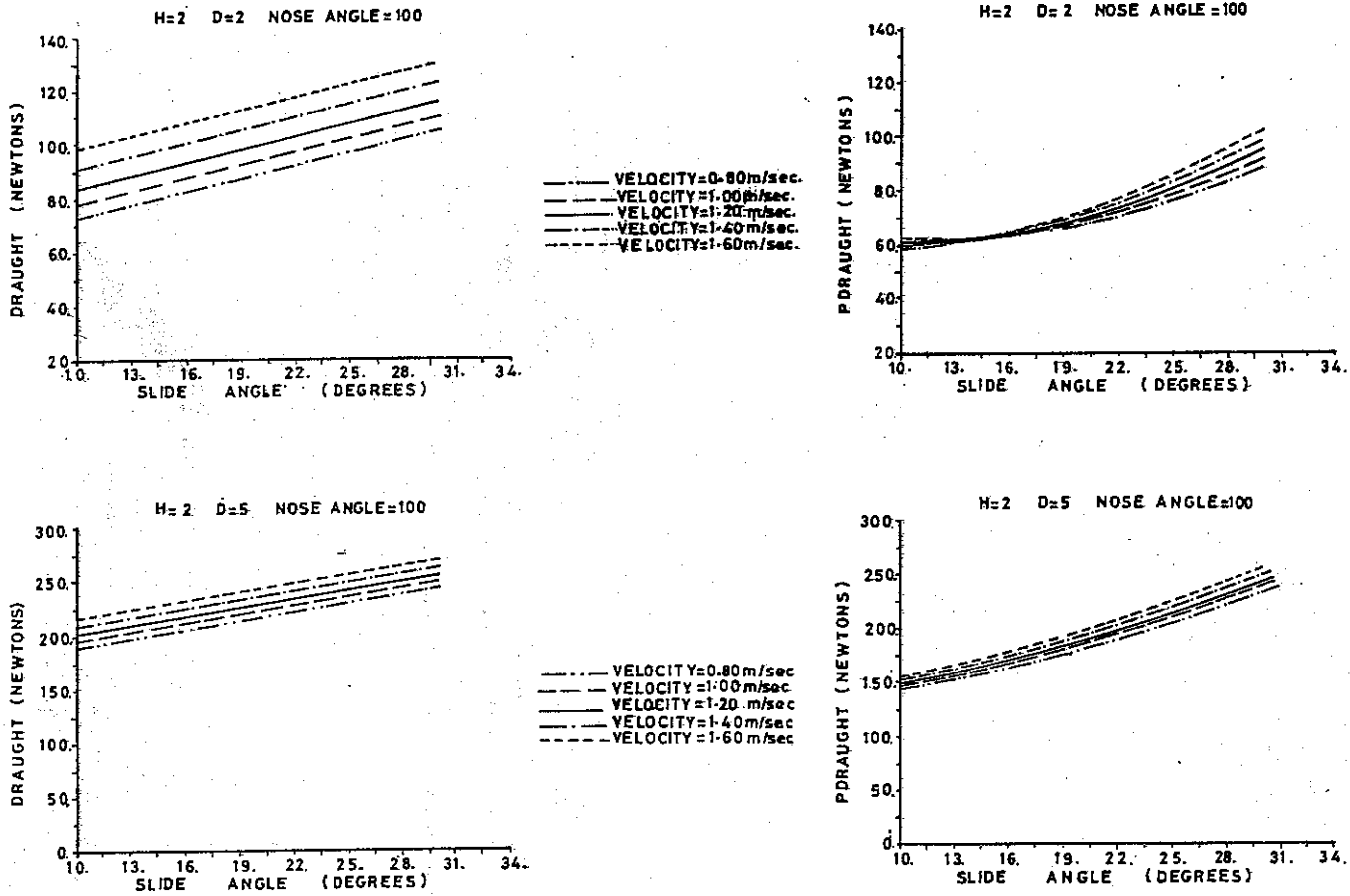

Fig. 4 Draught and Pdraught vs slide angle for levels of velocity

INNOVATIVE DESIGNS IN TILLAGE EQUIPMENT INCORPORATING POWERED PNEUMATIC CRUMBLER ROLLERS. PART I. MECHANICAL PERFORMANCE OF A PROTOTYPE CULTIVATOR.

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ABSTRACT

Farmers' requirements for tillage equipment have changed due to the increased necessity to incorporate straw. It is clear that in order to successfully incorporate straw a number of objectives have to be met, the requirement for chopped straw and other residues to be intensively mixed within the top 100 - 150 mm layer of soil, providing good soil/straw contact. Excessive moisture loss needs to be prevented within a system that can be operational as soon after harvest as possible with a high work rate so that the potential detrimental effects of decomposition do not affect the following seed.

The demand for a high output system has led to an increased power demand. The main restriction when using draft implements is the relatively poor utilisation of the tractor's engine power. This paper examines the principle of incorporating a driven pneumatic crumbler roller acting as a fifth wheel within a cultivator design. The potential benefits of such a system are illustrated through one design of straw incorporation cultivator. Further examples of how this principle could be adapted for further machines are illustrated and discussed in Part II of the paper.

INTRODUCTION

Agronomic and Mechanical Considerations of Straw Incorporation

Results of research work and commercial practice reveal that annual straw incorporation need not necessarily be tantamount to yield losses provided that appropriate techniques are employed. There are two main aspects to consider, firstly from an agronomic point of view and secondly as a mechanical process. Regular straw incorporation can bring about long term benefits to the soil by increasing the soil organic matter content which in turn improves soil structure causing improved aeration and drainage. Soil micro-organism activity is stimulated helping to form and stabilize soil aggregates [01], hence soil workability is improved especially on clay soils. Water retention is also increased as humus can hold up to ten times its own weight of water.[02]

In Scotland and Northern England greater soil wetness restricts the time available for straw incorporation and increases the likelihood of anaerobic soil conditions and microbial toxins. In combination with lower soil temperatures decomposition rates are slowed so that the period of 4 to 6 weeks required between straw incorporation and seeding the following crop is difficult to maintain. This period is generally recognised as being required if yield losses are to be avoided. [03]

One major problem to be avoided is that of soil pests, especially slugs. Slug problems have already been encountered where shallow incorporation methods provide increased shelter and food for slugs [01], while a rough, insufficiently consolidated seedbed with plenty of air spaces facilitates slug movement which in turn leads to increased damage [04]. Disease problems have been reported, however good control can be achieved in all systems.

The physical presence of straw may cause yield losses by impeding machinery and drilling equipment leading to poor germination and establishment. The design of equipment is very important and the problem of dealing with straw should be taken into account when selecting machinery. Often minor modifications can make a big difference to a machines performance.

An Improved Cultivator for Straw Incorporation

Ridges 1992 [05] demonstrated the mechanical feasibility of the original design idea, while Doerkes 1993 [06] optimised the design and tested it. Figure 1 illustrates the design of Doerkes. The machine is a two row rigid tine cultivator equipped with a driven tyre roller at the rear. The transmission line consists of a PTO drive shaft, connecting the tractor PTO to the input shaft of a gearbox mounted on the cultivator frame. The output shaft of this right angled gearbox is connected to a shaft which led to the left-handside of the cultivator, accommodating the driving sprocket for the chain drive of the roller. For the purposes of experimentation the transmission ratio could be changed by means of different gear combinations.

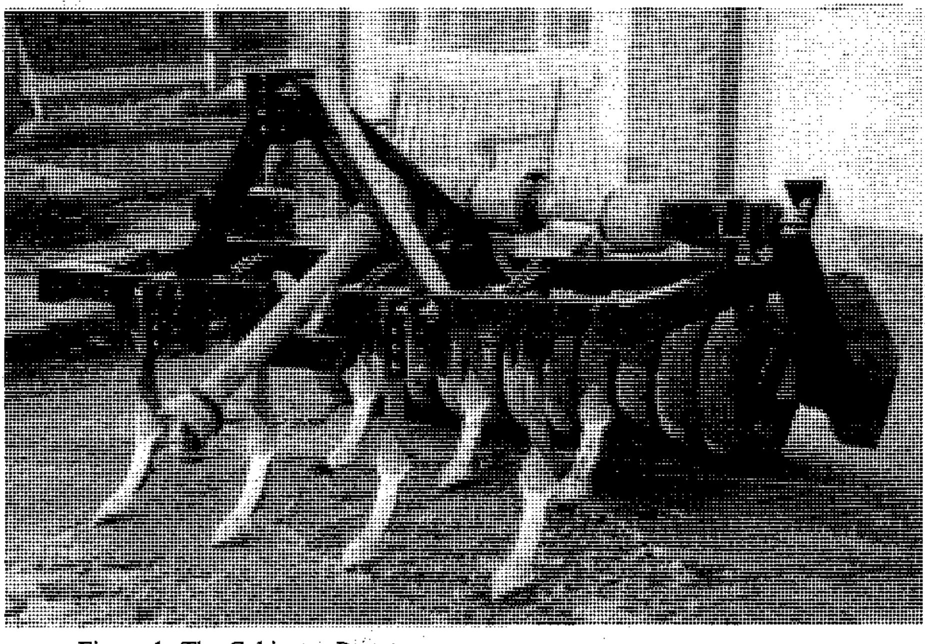

Figure 1. The Cultivator Prototype.

MATERIALS AND METHODS

The main design objectives were for an intensive and even mixing of straw within the soil as well as an intimate soil/straw contact. The following design features were incorporated:

- rigid tines were used rather than spring tines because the latter do not maintain their set depth of work and may pose problems with penetration in hard soil.

- a distance of 700 - 750 mm between the cultivator points and the base of the frame is required to avoid blockages.
- a lateral clearance of 200 - 250 mm between the cultivator tines guarantees sufficient penetration and loosening as well as mixing the straw and soil within the entire working width of the cultivator.
- the attachment of the driven roller at the rear is essential for consolidating the top layer of soil resulting in an intimate soil/straw contact.

All hitch points were manufactured to British Standard (BS)1841 part I for category II implements. The tines were protected from overload by shear bolts (M12 * 70 - 8.8), a distance of 150 mm from the pivot point to the shear bolt was selected according to the manufacturers recommendation. An overload protection device was also placed in the transmission drive line between the tractor and right angled gearbox.

Determination of Transmission Ratio

The basis for the calculation of the transmission ratio was the kinematic characteristics of the Zetor 7211 tractor used in the field trials. It was found that the ratio of wheelshaft to PTO shaft remains constant for all gears (1 - 5) in one range. As the appropriate speed for operating the cultivator in the field was 8 -10 km h^{-1}, the high speed range was used for all calculations, at an engine speed of 2200 min^{-1} the theoretical forward speed of the tractor in gears 1 and 2 is 8.25 km h^{-1} and 10.73 km h^{-1}. The tractor was a 30 km h^{-1} version equipped with 16.9 - 30 rear tyres.

In order to match the roller speed to tractor speed in gear 2, a speed of 10.73 km h^{-1} needs to be attained, assuming no slip between the tractor wheels and the roller. Then rearranging the formula for the circumferential speed of the roller

$$v_{roller} = \omega_{roller} * r_{dyn} \quad (1)$$

$$= 2\pi n_{roller} * r_{dyn} \quad (2)$$

where r_{dyn} = dynamic radius of the roller

The roller speed n_{roller} :

$$n_{roller} = \frac{v_{roller}}{2\pi r_{dyn}} \quad (3)$$

Solving for equation (3) $v_{roller} = 10.73$ km h^{-1}

$r_{dyn} = 0.286$m

gives $n_{roller} = 99.5$ min^{-1}.

The tractor PTO shaft revolutions are: $n_{PTO} = 493.9$ min^{-1}, the overall transmission ration i yields

$$i = \frac{n_{PTO}}{n_{roller}} = 4.96 \quad (4)$$

The space available to the chain drive to the roller is limited and the maximum ratio possible was 3 : 1. A gear ratio of at least 1.65 : 1 had to be supplied from the gearbox. A WALTERSHEID bevel gearbox with a gear ration of 1.92 : 1 was available which subsequently required a ratio of 2.58 : 1 in the chain drive to the roller. Within the experiment there was the requirement to drive the roller at different speeds in relation to the forward speed, this was achieved by using different sprockets on the chain drive,with ratios of 2.77 : 1 having 6% skid and 2.4 : 1 producing 7.6% slip of the roller relative to the tractor rear wheels.

Dimensioning the Power Transmission Line

In order to select the drive line component it was necessary to calculate the roller's power requirement. This can be obtained as follows:

Using the formulae $F_{xroller} = \mu * F_{zroller}$ (5)

$M_{roller} = F_{xroller} * r_{dyn}$ (6)

where $F_{xroller}$ = propulsive force of the roller (5395.5 N)
μ = adhesion coefficient (0.5) [07]
$F_{zroller}$ = weight of the roller
M_{roller} = resulting moment of the roller
$r_{dyn} = 0.286m$

finally yields $M_{roller} = 772$ Nm

Hence the power requirement for the roller (assuming no weight transfer) can be obtained from: $P_{roller} = M_{roller} * 2\pi n_{roller} = 8044$ W

Knowing the relative speeds of the shafts in the transmission system it was possible to calculate the torque in each element and size components accordingly. The actual torque in the output shaft was calculated as approximately 300 Nm. This calculation assumes that only the cultivator's own weight is supported by the roller, dynamic effects occurring when the cultivator was in use were not calculated. Bearing this fact in mind a safety factor greater than two was used. The gearbox selected had an output shaft torque of 1100 Nm rather than the next smallest unit which had an output torque of 600 Nm. The entire specification of the gearbox supplied by WALTERSHEID is GT 50 T - 1.93; 1 - $1/1^{3/8}$"(6) - $2/1^{3/8}$" (6) - 3 / $1^{3/8}$". A ratchet clutch K 35 B was chosen and calibrated to match the output torque of the chain drive. The chain drive was a 25 mm (1") pitch, using 13, 14 and 15 tooth sprockets at the driving gearwheel and a 36 tooth sprocket for the driven gearwheel to provide the ratios necessary.

Data aquistion system

In order to evaluate the performance of the cultivator the draught force, forward speed and torque in the transmission line were measured. The three point linkage dynamometer used in this experiment was developed at the Cologne Fachhochschule [08] over a period of years. The system did not change the geometry of the three point linkage system of the Zetor tractor, although the original bottom link were replaced. The bottom links were modified to accommodate transducers sensing horizontal and vertical forces. Strain gauges were attached to the toplink and the lateral guide of one bottom link in order to measure horizontal and lateral forces, respectively. The angle of the liftarm was indicated by means of a potentiometer. The torque needed to drive the roller was measured by means of an off-the-shelf torque dynamometer inserted into the power transmission line between the tractors PTO and the implement. The amplifier system as well as the tape recorder were accommodated in an instrumentation box bolted to the rear of the tractor cab. Power supply for the instrumentation was supplied by means of a HONDA ac/dc power generator mounted to the front of the tractor. The system was calibrated prior to experimentation.

RESULTS AND DISCUSSION

The field trials were carried out on wheat stubble. The soil properties of the trial plots were calculated according to British Standard (BS) 1377. The particle size distribution was 50.4 % sand, 25.2 % clay and 24.4 % silt. The moisture content was 25.4%. The straw yield was determined on the basis of whole crop sampling, where a number 1 m^2 samples were cut, threshed and the straw weight calculated. The average straw yield was 8.8 t ha^{-1}.

Twelve different run types were carried out, three working depths were used, 160 mm, 120 mm and 80 mm. With three driven replications at each gear ratio and three with the roller undriven. Making a total of 36 runs in the experiment, each run was 100 m long. For analysis a common number of samples from each run was thought to be necessary. Two hundred and thirty samples were taken from each measuring channel, the replicates were combined to give 690 sample points for each experiment. The overall draught force and torque was calculated for each cultivator configuration as well as the average forward speeds. These figures are illustrated in Table 1. The different cultivator configurations outline a difference in draught force requirement of 15 - 20 % when comparing the driven roller versions to the undriven one. At the 160 mm working depth the difference is more significant, 18 - 24 % The draught force requirement decreases with an increase in roller speed but the difference between the driven versions is not statistically significant, this applies to all working depths

It was intended to evaluate the cultivator's performance on the basis of power requirement. Unfortunately the tractor was not capable of pulling the cultivator at the desired speed of 8.1 km h^{-1} at the 160 mm working depth. The additional load imposed on the tractor meant that the engine speed was reduced, this reduction was not measured and so the PTO speed was not known. A direct comparison of the cultivator's power requirement was carried out for the 120 and 80 mm depths. The results are illustrated in table 2. The reduction in tractive power requirement is 13 - 21 % when driving the roller, whereas the overall power requirement of the driven roller configuration is 22 - 45 % higher than the power requirement of their respective undriven equivalent. It is further clear that there is a significant dynamic effect on the roller from the cultivator. Based on the assumption of no dynamic effect the anticipated PTO power was calculated as 8.044 kW, the actual values gained from experimentation indicate level of between 12.4 and 22.9 kW , indicating a substantial weight transference onto the roller.

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Run Type	Working Depth mm	Transmission ratio	Draught Force N	Torque Nm	Av. Speed km h^{-1}
1	160	2.77	21744	360	6.1
2	160	2.57	21188	424	6.4
3	160	2.40	20340	469	6.0
4	160	-	26548	-	5.9
5	120	2.77	18473	308	8.0
6	120	2.57	17896	374	8.1
7	120	2.40	17423	443	8.1
8	120	-	21669	-	7.8
9	80	2.77	12430	239	8.1
10	80	2.57	11923	301	8.1
11	80	2.40	11597	425	8.1
12	80	-	14659	-	8.1

Table 1 Average draught force, torque and tractor forward speed for run type 1 -12.

Run Type No.	Tractor Power kW	PTO Power kW	Overall Power kW
5	41.1	15.9	57.0
6	40.3	19.5	59.8
7	39.2	22.9	62.1
8	46.9	-	46.9
9	28	12.4	40.4
10	26.8	15.6	42.4
11	26.1	22.0	48.1
12	33.0	-	33.0

Table 2 Power requirement of the cultivator at the working depths of 120 and 80 mm

INNOVATIVE DESIGNS IN TILLAGE EQUIPMENT INCORPORATING POWERED PNEUMATIC CRUMBLER ROLLERS. PART II. SOIL EFFECTS AND FURTHER APPLICATIONS

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ABSTRACT

The mechanical performance of a high output machine for straw incorporation which utilises a powered pneumatic roller is described in Part I of this paper. The design is offered as a possible method of improving the utilisation of available power from a tractor thus reducing the need for heavier tractors and draught equipment.

The second aspect of the cultivator's performance is its effect on the soil. The machine gives a higher proportion of smaller aggregates when the roller is in the driven mode. Experimental results are discussed and further ideas on utilising the principles behind the design are illustrated. The two main tenants of the design are, a) better tractor utilisation and b) improved tilth production.

INTRODUCTION

The overall performance of the cultivator had to be assessed. Operating at a speed of 8 km h^{-1} the loosening of the top layer of soil as well as its mixing with straw and stubble was excellent for most cultivator configurations. An exception was when working at a depth of 80 mm, which proved to be insufficient in places as strips of soil and stubble between the tine furrows remained unpenetrated.

It was also obvious that a decrease in working depth caused an increasing amount of straw to remain on the soil surface. There was a striking difference between the driven versions and the undriven version of the roller relative to the soil surface. The driven roller provides a much more even and consolidated soil surface than the undriven version, resulting in improved soil / straw contact. This observation was made for all working depths. No significant differences concerning the soil surface were observed among the different driven versions.

A further merit of driving the roller was the much better self-cleaning effect in comparison to the undriven version. In this case, problems were encountered with soil sticking to the roller adversely affecting it's performance. No scrapers were provided for the roller and at no time while the roller was being powered were problems of soil build up encountered despite further tests being carried out under conditions of high soil moisture content.

Where it was not possible to maintain the recommended operating speed of 8 km h^{-1}, the mixing of soil and straw within the profile was not intensive enough and small straw pockets developed in the areas of the tine furrows.

MATERIALS AND METHODS

The roller's effect on the top layer of soil was evaluated by means of a comparison of the aggregate size distribution caused by the different treatments. For statistical analysis of the aggregate size distribution six samples were taken for each of the twelve treatments. A 300 x 300 mm square sampler was manufactured for this purpose. The sampler was pressed into the soil, once at its full depth a plate was inserted horizontally into the sampler at a depth of 80 mm. The sample was removed for drying and sieving. Using a set of British Standard (BS) test sieves with the aperture sizes of 75, 63, 50, 37.5, 28, 20, 14, 10 and 6.3 mm the aggregate size distribution was determined for all samples.

For the purposes of graphical representation the clod sizes were classified corresponding to the sieves.

Class No.	Clod Size [mm]
1	>75
2	75....63
3	63....50
4	50....37.5
5	37.5....28
6	28....20
7	20....14
8	14....10
9	10...6.3
10	<6.3

Table 1. Correspondence between class number and clod size.

The basis for comparison was the percentage by weight in each sieve class. Due to the large amount of data a series of diagrams were created that compare the different cultivator configurations at each working depth. Figure 1 contains data for the 160 mm working depth where each of the ten classes contains four bars representing the different transmission configurations and the percentile aggregate size distribution by weight.

RESULTS AND DISCUSSION

Regardless of the working depth a similar pattern emerged where the driven roller versions had a significantly higher number of aggregate less than 6.3 mm compared to the undriven equivalent. The differences measured were 8 - 15% of sample weight. The differences in classes 1 - 3 which contain the larger aggregates show a higher number of these with the undriven roller, in this case the difference is 2 - 4 % of sample weight.

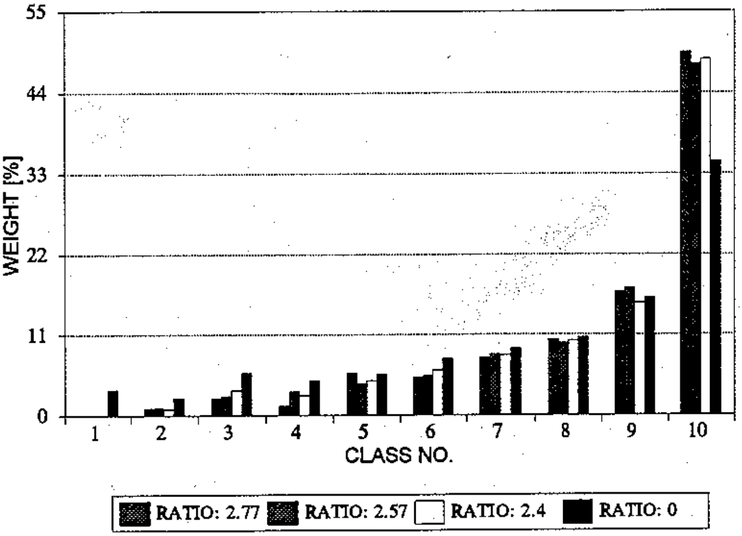

FIGURE 1 AGGREGATE SIZE DISTRIBUTION
WORKING DEPTH: 160 mm

A oneway analysis of variance of the data was conducted using MINITAB [01] statistical software so as to test whether the influence of the cultivators transmission configuration on the aggregate size distribution was statistically significant. Firstly, each driven configuration was compared to the undriven roller version at the respective working depths of 80, 120 and 160 mm. A further comparison of all the driven roller versions was also made. On the basis of individual 95 % confidence intervals a statistically significant difference was proved when comparing the three driven roller versions to the undriven one in clod size 1,2,3 and 10. Considering the statistical analysis on the basis of comparing the individual driven roller configurations no statistical significance could be proved between the treatments. when driving the roller matched to tractor speed, powering the roller with 6% skid and 7.6% slip. This fact is important in relation to the differences in power input to achieve these conditions.

The visual impression of the soil immediately after cultivation revealed the much better performance of the cultivator with the roller being driven. The surface was more even as well as better consolidated. The reason for this phenomenon was thought to be the more intensive shearing of the soil aggregates when driving the roller.

Driving the roller at the same speed as the tractor rear wheel was found to be the best configuration as driving the roller either faster or slower caused additional load on the transmission line which in turn reduced the tractor engine speed with no improvement in working effect. It had been thought at the outset of the project that by driving the roller faster than the tractor extra shear under the roller would give better soil breakup for this series of experiments, this was found not to be the case.

Design improvements are being considered in relation to the actual roller. The idea of using car tyres was attractive from the point of view of cost and weight. The design depends on the tyres being held together in compression by means of four tie rods located through the wheel centres which were used to compress the roller pack. The tie rods were attached to a fixed welded roller hub at one end. At the other end of the drive shaft a moveable hub was located on a keyway. This allowed the roller pack to be drawn together and held under compression. The walls of the tyres provided sufficient resistance to torsion that light weight tie rods could be used. This worked satisfactorily if no more than one puncture was sustained at any one time, if more punctures occurred then compression was lost and the torque in the roller pack had to be taken up by the tie rods which would result in damage. The original design satisfied the objectives of being light and inexpensive but perhaps a more robust design needs to be considered. The principle of the design used is high-lighted in figure 2 where a sectioned view of a design of a front mounted 4 m pneumatic roller is suggested. The construction of the actual roller is highlighted and the implement framework is not shown. The 95 kW tractor has been placed behind the roller to give a sense of scale.

Further work is being carried out to examine the energy inputs of cultivation equipment in order to evaluate the most energy efficient ways of establishing a seedbed. It is clear that the timing of operations is very important. It is intended that a system such as the one proposed could be utilised to improve the timeliness of winter cereal operations. Farmers are more and more concerned with completing operations as quickly as possible so as to cultivate when the soil is likely to be drier, therefore avoiding soil damage and expensive remedial work. Early cultivation generally mean operation are carried out while soil temperatures are higher allowing straw decomposition to begin immediately. It is also important that cultivation methods should avoid excessive moisture loss, the system proposed satisfies these agronomic requirements.

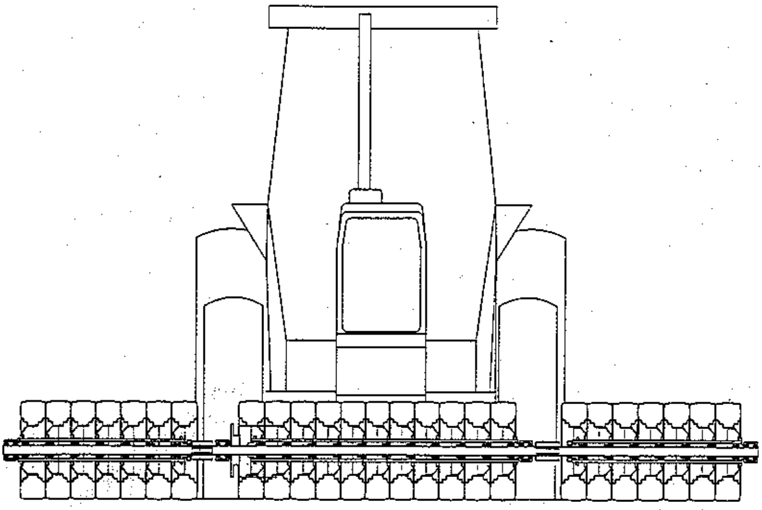

Figure 2. Schematic diagram of Tractor with Sectioned Roller

One factor to consider is the improvement of a tractor's tractive effort when using draught equipment as this is the main limiting factor to improving machine performance. With this in mind a number of designs have been produced which utilise the power driven pneumatic roller. Other designs for primary tillage tools have been produced, these use the original operating principle of the prototype cultivator but operate in combination with discs as well as tines. Secondary cultivation machines include a front mounted powered roller with multi-harrow which can be used in combination with either a rear mounted drill for lighter soil conditions, a cultivator unit or a drill/cultivator where further cultivations are required. The rear mounted unit would not be a powered cultivator, as it is intended to maintain high operating speeds with draught equipment. These designs will be illustrated fully in the oral presentation.

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SOIL TOOL DESIGN INFLUENSE ON DRAFT FORCE

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ABSTRACT
This paper will attempt (1) to show the relation between the design of different cultivator tines and draft force requirements and energy consumption by means of measurements and design; and (2) to describe how alternative materials can be used for the manufacturing of cultivator tines. Various measuring results show that flexible tines will result in lower energy consumption.

INTRODUCTION

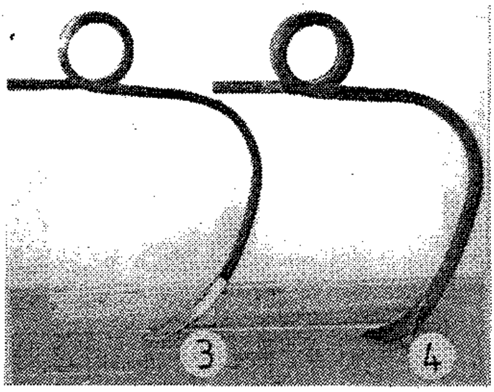

Fig. 1: Cultivator tines, type Vaks and type Bulldog

In the spring of 1992 a project was carried through with the object of carrying out measurements regarding different harrow tines. The aim of the project was to describe the draft force requirements and energy consumption of different harrow tines under certain conditions such as: speed, depth and soil characteristics. The project included, among other things, two types of stubble harrow tines.
The two types of tines in question were made of steel of different thicknesses.

One type - designated Vaks - was made of 25 * 25 mm steel. Made of 32 * 32 mm steel, the other type was designated Bulldog. As will appear from fig. 1, the two types of tines were designed with identical geometry. However, the two tines had different spring characteristics under static load due to the difference as regards materials dimensions, cf. fig. 2.

MATERIALS AND METHODS
Force measurements were carried out by means of a measuring vehicle, as illustrated in fig. 3. The actual measurements were carried out by means of a so-called "octagonal ring transducer" in order to make it possible to distinguish between horizontal and vertical forces. [1].
Field measurements are carried out as follows: a strain gauges amplifier receiving signals from the transducer is mounted on the tractor. The signals are stored on a data recorder via the amplifier. The signals are subsequently processed on a PC in the laboratory so that force-time graphs can be printed out. [2].

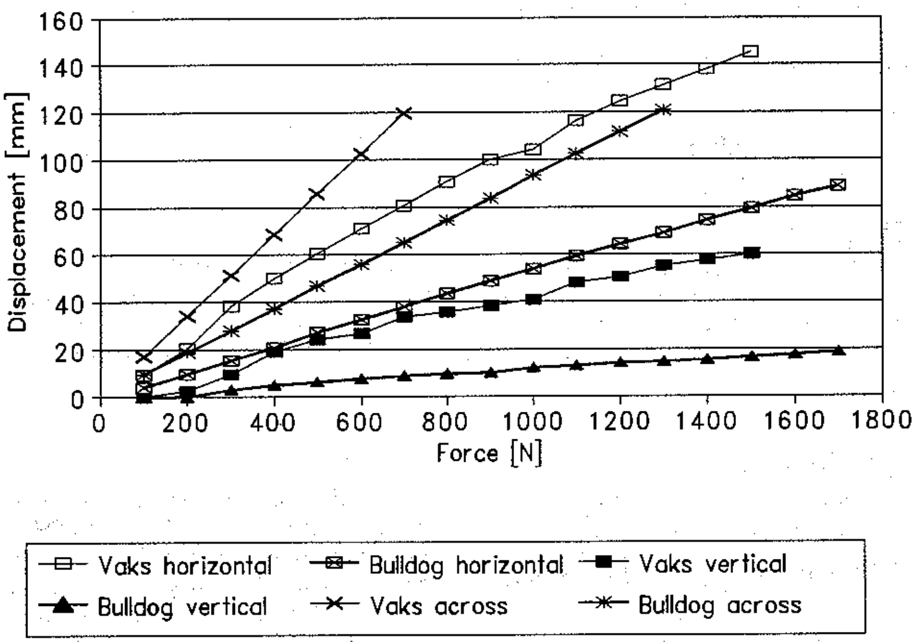

Fig. 2. Cultivater tools with flat blades

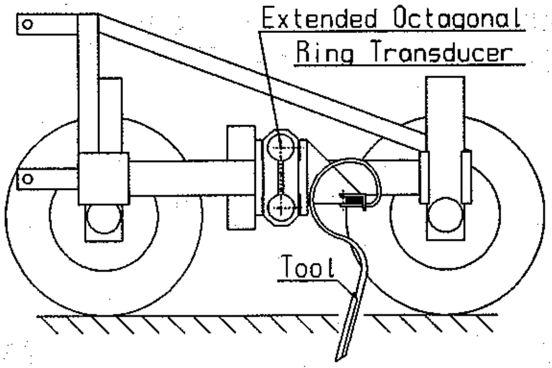

Fig 3. Measuring vehicle with a single tool for soil tillage

Calibration of instruments

The instruments were calibrated prior to the field measurements. The measuring vehicle is designed to permit dismounting of wheels and the three-point linkage, after which the remainder of the measuring vehicle, including transducer and tine, is placed in a large calibration fixture. Static calibration was completed to ensure accurate correspondance between the output voltage of the strain gauge amplifier and the horizontal/vertical forces on the octagonal ring transducer. The tractor speedometer was also calibrated.

RESULTS

Due to the time of year there were no suitable fields available where the tines could be exposed to the type of loads they were designed to sustain. The field measurements were consequently carried out in sown, but loose soil with soil moisture amounting to approx. 20% water.

The texture analysis showed:

16.5 clay
15.5 silt
36.9 fine sand
28.8 coarse sand
2.3 humus

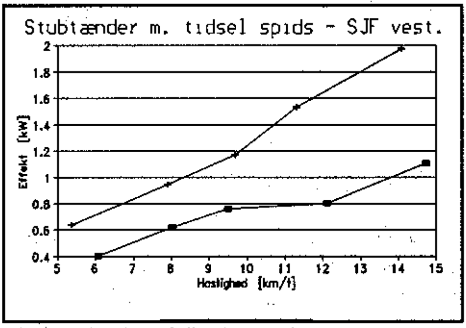

Fig. 4 Results of field experiments

The résults of the field experiments were computer processed using statistical methods.

The results were surprising since Vaks appeared only to require approx. 50% of the energy consumption required by Bulldog. The field experiments were repeated and showed the same trend as the experiment illustrated in fig. 4.

The two harrow tines performed exactly the same operation, were equipped with the same cutting blade etc.

DISCUSSION.

The test results caused a good deal of discussion since there may be several possible explanations for the difference in energy consumption.

The most immediate explanation is that Vaks vibrates more and therefore works more easily in the soil. It is also possible that both harrow tines are caused to oscillate and that it takes more energy to sustain oscillations in Bulldog owing to its greater rigidity and mass. Another possibility might be that the two harrow tines simply do not perform the same work. Suppose that the two tines come across a stone. Due to its flexibility Vaks will evade the stone whereas Bulldog simply moves the stone, thus requiring somewhat more energy. In the last-mentioned case, whether the two tines perform the same work becomes a question of yields.

<u>A flexible harrow tine</u>

Since the two harrow tines performed the same work in the field, but had different power requirements, the idea sugggested itself that it might be worthwhile to design a harrow tine featuring the properties of Vaks to a marked degree.

In the first instance this required work focusing on the spring characteristic of a harrow tine offering optimum properties in theory.

This is illustrated below in the form of a graph showing the vertical travel of the harrow tine in relation to the horizontal force (fig. 5).
The "ideal spring characteristic" is a hypothetical model offering the advantage that the tine will evade any major obstacle under the same load as Vaks (approx. 900 N), thus yielding lower peak values. This is not substantiated by the theories of soil dynamics, but follows logically from the fact that a flexible harrow tine requires less energy that a rigid tine.

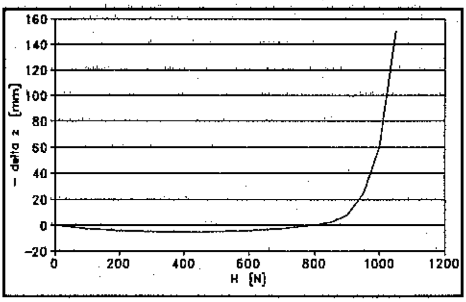

Fig 5. The ideal charasteristic

A lightweight harrow tine

Since the possibility could not be ruled out that the mass of the harrow tine may also be important as regards power consumption, it was logical to try to design a lightweight harrow tine offering high flexibility. In consequence of the deliberations described above in the section on the flexible harrow tine, a project was initiated with the aim of designing a lightweight harrow tine with the ideal spring characteristic.

Design of a lightweight harrow tine

In order to design a lightweight harrow tine with very good flexibility, materials with low specific rigidity and high specific strength are needed. Fibre glass was chosen as the material which best fulfils these criteria, consideration being had to required strength and costs. It was decided to use a Rowings-type E-fibre glass with epoxy as the matrix material [PRE PREG] for the construction. This is the type of material used for manufacturing the rotor blades of wind turbines.
The next step was to design the harrow tine so as to enable it to comply with the requirements of the ideal spring characteristic.
For this purpose a computer programme was developed that calculates the deflections of a harrow tine configuration when exposed to certain forces. This programme was used to design the harrow tine.
As it is not immediately possible to create the ideal spring characteristic due to the fact that such a harrow tine will invariably show rectilinear deflection when exposed to horizontal forces, it was also necessary to allow for the vertical forces in designing the harrow tine.

In this connection reference is made to the theory of soil dynamics, which describes the relation between rake angle and vertical forces.

It is possible to imitate the ideal spring characteristic if the rake angle is allowed to change proportionally to the horizontal force to reach the point where the vertical forces change from drawing the harrow tine downwards to pushing it out of the soil. If this point is reached at approx. 800-900 N, the soil and any earthfast stones will quickly cause the harrow tine to reduce operating depth. According to calculations of soil dynamics this point will occur between 60 and 70 degrees for most types of soil. Another factor which may cause the harrow tine to offer the right spring characteristic is the cross section shape. A cross section can be designed in such a way that its moment of inertia is reduced as deflection occurs. In this instance a curved cross section was chosen because one of its properties is that it straightens out when the "beam" is bent.

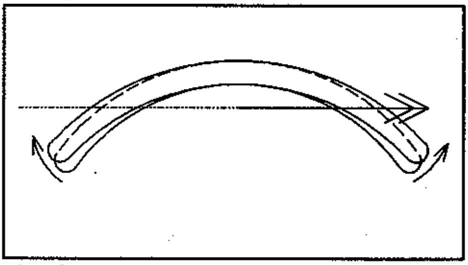

Fig. 6 The shape of the cross section

Testing of the new harrow tine

Tests of the new lightweight harrow tine have been carried out by means of the measuring vehicle and it performs reasonably well in the field. Unfortunately, it has not been possible yet to carry through comparative measurements between the new design and existing harrow tines. Therefore there is no evidence available to support the assumption that the new harrow tine will require less energy than "conventional" harrow tines, but hopefully such measurements will soon become available to provide a basis for further development work.

PERSPECTIVES

Based on the above presuppositions, the new harrow tine may enable the farmer to operate a bigger harrow without having to invest in a bigger tractor as well. Moreover, the new harrow tine offers energy savings, which is a significant advantage today. In conclusion, it should be pointed out that the weight of a fibre glass tine is approx. 30% of the weigth of a similar harrow tine made of steel. Moreover, the fibre glass tine offers better strength and longer service life.

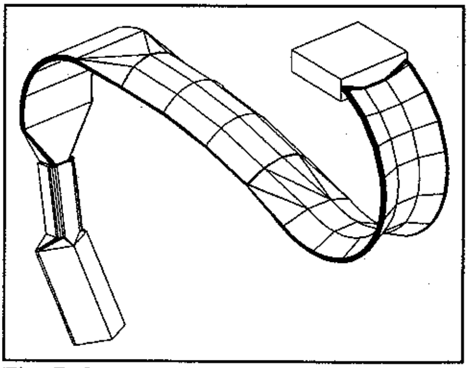

Fig. 7 3-D schetch of the new harrow tine.

Notes:

[1] Octogonal ringtransduser (Sweden)

[2] Design of Agricultural Machinery, Jørgen Maagaard Pedersen, Paper III-22 from 92-ICAE Conference in Beijing, ISBN 7-800003-199-3/s125.

EFFECTS OF TILLAGE SYSTEMS AND SEED COULTERS ON SEEDBED PROPERTIES AND YIELD OF CEREALS

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ABSTRACT

Reduced tillage has been in focus of research in Sweden for the last two decades aiming to cut production costs, to improve soil properties and to reduce evaporation during the spring, and it is presently gaining interest among farmers. However, large amount of straw at or near the soil surface often causes problems for conventional seed coulters when seeding. On two clay soils, comparisons were made between a conventional drill with share coulters and two drills with duckfoot coulters, JB-Special (width 130 mm) and Ekoodlaren (width 400 mm). The coulters were tested in three primary tillage systems (mouldboard ploughing, shallow tillage, no-till) as well as after different harrowing intensities. Effects on seedbed properties, seed placement, plant emergence and crop yield were investigated. The results showed few significant differences between seed coulters in seedbed properties. The conventional coulter gave the highest plant emergence, but the yield was highest after the JB-Special drill.

INTRODUCTION

Less time and energy consuming tillage operations are required to save energy and to decrease crop production costs, but also to minimize environmental impact of agriculture. Still, good crop establishment and growth are important. Reduced tillage depth increases soil aggregate stability, soil organic matter in surface layers, and air and water permeability (1, 2). In ploughless tillage systems, besides high bulk density in the central topsoil layer, an important problem is that the amount of straw at and near the soil surface at sowing may be too high for conventional seed coulters (1, 2). New tillage and seeding implements are constructed to meet the requirements. In this study, the effects on seedbed properties, and on crop establishment and yield of three drills are compared in different tillage systems. The field experiments were supported financially by the Swedish Farmers Foundation for Agricultural Research.

MATERIALS AND METHODS

Experimental sites and design

Two field experiments with four blocks were conducted on clay soils near Uppsala, Sweden. Except for direct-drilled plots, both sites were stubble cultivated once in the autumn 1991, before primary tillage treatments were imposed.

In site 1 (56 g clay and 6.5 g organic matter per 100 g soil), in a split-split plot design, two primary tillage treatments (mouldboard ploughing to 25 cm depth and stubble cultivation by 2 passes with a spring tine cultivator to 13 cm depth) were conducted in the autumn 1991, and three seedbed preparations (zero, one and three passes with a spring-tine harrow) were performed in the spring 1992. Harrowings were allotted to main plots and primary tillage treatments to subplots. Three seed drills were assigned to sub-sub plots with an area of 3.3 x 20 m, viz.:

- Nordsten - a conventional combi-drill with share coulters. The working depth is controlled by interaction between the soil resistance and coulter-spring pressure. Row spacing is 12.5 cm. Fertilizer coulters are mounted in front of the seed coulters in the center of every second inter-row.

- JB-Special - a prototype combi-drill designed for reduced tillage but also for use after conventional tillage and as a direct drill. The coulters consist of 13 cm wide duckfoot shovels, placed 25 cm apart, each seeding two narrow bands at 12.5 cm distance. Fertilizer is delivered from the front center and is placed 1 cm deeper than the seed. Depth is regulated by a spring and a depth control wheel. The seed is transported by air.

- Ekoodlaren - is constructed for seedbed preparation, fertilizing and row-weeding in single or combined operations. The 40 cm wide duckfoot shovels, each mounted on a bogie, place seed in twin bands 16 cm apart and 20 cm between double bands. Depth is controlled by bogie mounted wheels. The seed is transported by air.

In site 2 (42 g clay and 4.7 g organic matter per 100 g soil), in a split-plot design, three main treatments (autumn mouldboard ploughing with conventional seedbed preparation, autumn stubble cultivation with conventional seedbed preparation and direct drilling) were combined with the same three seed drills as in site 1 allotted to subplots with an area of 3.3 x 20 m. However, in direct-drilled plots, the Nordsten was replaced by a Bettinson direct drill. Seedbed preparation was done by three passes of an S-tine harrow.

In site 1, ammonium sulfate (78 kg N ha^{-1}) was combi-drilled with the Nordsten and JB-Special but broadcasted with the Ekoodlaren, and in site 2, it was broadcasted in all cases. In both fields, about 400 seeds m^{-2} of spring barley (*Hordeum vulgare* L.) were sown on 15 May 1992. A post-emergence herbicide was applied according to local recommendations. Harvest was done on 7 September in site 1 and on 30 August in site 2. Monthly precipitation and potential evaporation for 1992 and means for a 30-year period were obtained from Uppsala Meteorological Station, 10 km west of the experimental sites (Table 1).

Table 1. Precipitation and potential evaporation during the growing season at Uppsala

Month	Precipitation (mm)		Potential evaporation (mm)	
	1992	Mean 1961-90	1992	Mean 1961-90
May	21.5	32.8	105.6	89
June	22.1	45.9	128.8	103
July	117.4	70.5	106.1	97
August	67.7	66.4	69.8	70
September	46.5	57.0	30.1	34

Measurements

Seedbed properties
Seedbed investigations were carried out near one end of each plot, between wheel tracks. This was done by sampling all loose soil within one 40 cm x 40 cm and one 25 cm x 40 cm area according to Kritz (3). Determinations included seedbed depth, soil moisture content in the seedbed, aggregate size distribution in three sublayers of the seedbed (L1-L3), roughness of the soil surface and the seedbed bottom, and seed depth distribution. The depth of the seedbed was estimated by measuring the volume of the removed loose soil in a way that does not significantly change the bulk density (3). The moisture content was determined gravimetrically. The aggregate size distribution was determined by sieving the soil in three aggregate size fractions: > 5, 2-5 and < 2 mm. Surface and bottom roughness was determined by measuring the highest and lowest point within the 40 cm x 40 cm frame. Seeds found in each sub-layer and in the seedbed bottom were counted to determine seed placement.

Moisture loss as measured by time-domain reflectometry
Time-domain reflectometry (TDR) was used to monitor volumetric soil water content (moisture loss) during the first three weeks after seeding in site 1. Measurements were taken from the mouldboard ploughed plots under 0 and 3 harrowings with the Nordsten drill. After removal of the loose seedbed from each plot, a pair of 17 cm long waveguides was pushed vertically to a depth of 10 cm and moisture content measured by a portable TDR unit, Tektronix 1502 TDR cable tester (4). In addition, at five occasions, dry bulk density was determined from cores (7.2 cm diameter, 10 cm high) sampled very close to the positions of the TDR-probes while the loose seedbed layer was removed, and was used to convert the volumetric wetness measured by the TDR into mass wetness.

Weed density, crop emergence and grain yield
Weed density and crop emergence were determined at Zadoks stage 13 (5) by counting the number of plants within a 0.25 m^2 area from both ends of each plot. Grain yield was determined in all plots from a 28 m^2 harvest area in the center of each plot and presented at 15% moisture content.

RESULTS AND DISCUSSION

In site 1 (Table 2), surface and bottom roughness were smaller with three harrowings than with one or zero. Ekoodlaren produced a rougher soil surface and a deeper seedbed with higher moisture content than the other drills despite that a 4 cm setting was used. Differences in moisture content in the seedbed and in the bottom were small and non-significant, except that Ekoodlaren, as a consequence of the deeper seedbed, also produced a more moist seedbed than the other drills. The proportion of aggregates > 5 mm in layer 1 (L1) was significantly larger in stubble cultivated than in ploughed plots. The number of harrowings had a non-significant effect on seedbed structure, and the type of seed drill had a minor effect. There were no differences between drills in seed placement, except that some seeds were found at the soil surface after the JB-Special, mainly losses caused by the seed transporting air flow (data not shown). More than 75 % of the seeds were in all cases placed at the seedbed bottom.

The year 1992 was dry with lower precipitation and higher potential evaporation than the 30-year average. Therefore, for good crop emergence, the seed had to be placed at an adequate depth and covered by a seedbed that provided a good evaporation control. Despite the small effect of harrowing intensity on seedbed structure, crop emergence increased with the number of

Table 2. Surface and bottom roughness, depth and soil moisture content in the seedbed, aggregates > 5 mm in layer L1-L3, crop emergence and grain yield in site 1, Uppsala, 1992

Treat-ment	Surface roughness (mm)	Bottom roughness (mm)	Seedbed depth (cm)	Water content[a] (g/100 g)	Aggregates > 5 mm (%)			Crop emergence (%)	Grain yield (kg ha^{-1})
					L1[b]	L2	L3		
Tillage									
Conv	53.4	23.6	4.3	25.15	53b	33	25	86.7	4800b
Stub	54.9	34.5	4.3	23.88	71a	42	26	82.8	5110a
L.S.	ns	ns	ns	ns	**	ns	ns	ns	**
Harrowing passes									
0	58.4a	43.2a	4.2	23.39	56	40	28	74.8b	4730b
1	57.6a	38.3a	4.7	25.02	66	38	27	88.8a	5040a
3	46.5b	5.5b	4.0	25.90	64	34	22	90.6a	5100a
L.S.	**	*	ns	ns	ns	ns	ns	**	*
Drill									
Nord	50.6b	20.8	3.8b	24.16b	57	32	21b	93.2a	4910b
JB	52.7b	39.2	3.9b	23.62b	64	41	26ab	77.4c	5120a
Eko	59.2a	27.0	5.2a	25.77a	65	39	30a	83.6b	4830b
L.S.	*	ns	***	*	ns	ns	*	***	***

L.S. (Level of Significance): * = 0.05 ≥ P > 0.01, ** = 0.01 ≥ P > 0.001,
*** = P ≤ 0.001, ns = not significant

[a] Soil moisture content at permanent wilting point = 22-23 g/100 g as estimated from an adjacent site with similar clay and organic matter content.

[b] L1-L3 represent three sub-layers of the seedbed.

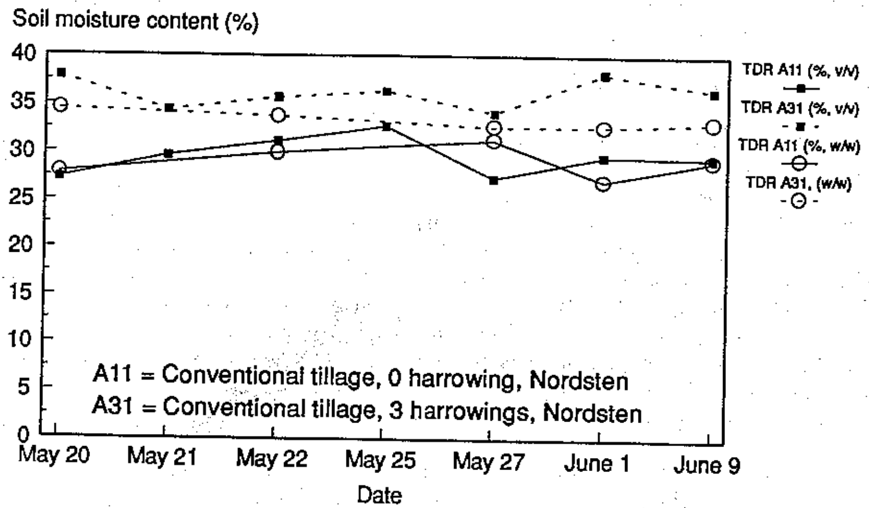

Figure 1. Soil moisture content as measured by TDR in site 1, Uppsala, 1992.

Table 3. Surface and bottom roughness, depth and soil moisture content in the seedbed, aggregates > 5 mm in layer L1-L3, crop emergence and grain yield in site 2, Uppsala, 1992

Treat-ment	Surface roughness (mm)	Bottom roughness (mm)	Seedbed depth (cm)	Water content[a] (g/100 g)	Aggregates > 5 mm (%) L1[b]	L2	L3	Crop emergence (%)	Grain yield (kg ha^{-1})
Tillage									
Conv	49.3	27.7b	4.88	19.7	34c	21b	14b	92.5a	4540
Stub	52.5	22.4b	5.22	20.1	46b	27b	17b	88.1a	4400
DD	61.4	41.4a	4.59	18.8	86a	71a	43a	55.9b	3960
L.S.	ns	*	ns	ns	***	***	***	*	ns
Drill									
Nord	47.5	24.8b	5.06	20.8	40	27	18	95.5a	4630
JB	52.8	36.7a	4.42	18.6	55	37	22	71.6c	4390
Eko	58.2	24.5b	5.38	19.8	56	41	26	82.6b	4150
L.S.	ns	**	ns	ns	ns	ns	ns	*	ns

L.S. (Level of significance): * = 0.05 ≥ P > 0.01, ** = 0.01 ≥ P > 0.001,
*** = P ≤ 0.001, ns = not significant
[a]Soil moisture content at permanent wilting point = 17-18 g/100 g as estimated from an adjacent site with similar clay and organic matter content.
[b]L1-L3 represent three sub-layers of the seedbed.

harrowings. This could be due to the sorting effect that brings large aggregates upwards and small aggregates closer to the seed (6) and increases the seed-soil contact, and to a general homogenizing effect of harrowing. Crop emergence differed significantly also between the seed drills. It was higher for Nordsten and lower for JB-Special than for Ekoodlaren. In stubble cultivated plots, emergence increased significantly more with increased number of harrowings than in mouldboard ploughed plots (data not shown). Grain yield was significantly higher after stubble cultivation than after mouldboard ploughing, incresed with the number of harrowings, and was significantly higher for JB-Special than for the other drills. The moisture contents measured by TDR showed that three harrowings significantly reduced losses compared with zero harrowing (Fig. 1).

The higher yields in combi-drill plots compared to Ekoodlaren at site 1 may be due to the effect of the fertilizer placement. In this region, placement of fertilizer in rows deeper than the seed has been shown to increase yield in dry years by several percent (7).

In site 2 (Table 3), the seedbed was generally deeper than in site 1, but with no significant differences between treatments. Seedbed bottom roughness was higher for direct-drilled plots than for the other tillage treatments, and higher for JB-Special than for the other drills. Moisture content showed no significant differences. The seedbed structure was significantly coarser in direct-drilled plots than in the others, and slightly coarser in stubble cultivated than in mouldboard ploughed plots. 56 % of the seeds were placed at the bottom after the Ekoodlaren compared to 81 % after Nordsten, but the difference was not significant (data not shown). The tillage treatments did not affect the seed placement either. Both crop emergence and yield were reduced by direct drilling, but the difference in yield was not significant.

In all treatments at both sites, there were more than 5 g plant available water per 100 g soil in the seedbed bottom. According to Håkansson & von Polgár (8) this may be expected to result in a fast and good emergence of small grain cereals in dry years, if the protective effect of the seedbed is adequate. Håkansson & von Polgår (8) suggested that this is achieved by a 4 cm deep seedbed dominated by aggregates < 4 mm. Braunack & Dexter (9) reported that increased aggregate size in dry years decreased yield of grain and total dry matter. In direct-drilled plots in site 2, the seedbed was dominated by aggregates > 5 mm and crop emergence was significantly lower than in tilled plots, but still, the grain yield was not significantly decreased.

CONCLUSION

The new drills tested in the experiments performed better than the conventional drill in reduced or zero tillage systems. However, to draw more general conclusions concerning their value, experiments in other sites and years are required.

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THE FUTURE OF ADAPTABLE SOIL TILLAGE IN HUNGARY

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ABSTRACT

In the 20th century, four trends have arrived to Hungary, namely the dry farming, minimum tillage, conservation and sustainable agriculture. The main feature of the trends was the overcoming of an unfavourable situation or adaptation to the situation.

The transition to the adaptable tillage, which is the basis of the adaptable plant production, is urged by the present difficulties of farming and the diminishing cultural state of the soil.

The question can be approached through the examination of maize soils. It was proved that under given farming conditions, some elements of a traditional cultivation system can be used only at great risk because the present soil condition damages can increase.

Primary soil condition damage of the examined maize soils was the compaction. Seven versions of compacting process were observable. The place of compaction in the soil layers proved the impossibility of traditional cultivation in the given situation.

INTRODUCTION

Out of the trends appearing in Hungary in the 20th century, four have played important role in the streamlining of farming.

At the turn of the century, the so-called "dry farming" theory of Campbell from North America and its tools (disk, deep compacting rolls) offered successful cultivation methods even under dry conditions (Birkás, 1994). The "Campbell craze" faded away after some 20 years. Today only a short paragraph reminds us of it in the textbooks.

The "minimum tillage" in the 1950s promoted to barmonize the favourable physical-biological condition of the soil and the decreasing cultivation costs (Hayes 1988, Schertz 1988). This trend has stimulated many experiments in Hungary. The results, however, did not have any impact on the practice.

The "conservation tillage" trend in the 1970s aimed primarily the protection of soil (Schertz 1988, Karlen 1990). It promoted the energy-efficient and soil-protecting attitude in 1980-1988.

The "sustainable agriculture", as the theory of reasonable, adaptable environmental management (Lal 1991, Pierce-Lal 1991, Ángyán 1991) is the subject of wide-range research, and basic concept of conferences and studies.

Our objective is not the analysis of the system, it has been done by many researchers. Its main feature is the improvement and conservation of the soil fertility and structure with biological and soil-protecting methods.

Why do we say that the adaptable soil cultivation, as a basic pillar of "sustainable agriculture" is necessary in Hungary? Partly because we can observe the signs of soil decay and partly because of the present situation of the agricultural production (decreasing productivity, losing markets, diminishing cultivation culture, etc.) In the present study we examine the possible future of adaptable cultivation in Hungary and its main features, using the cultivation of the maize as a sample.

MATERIALS AND METHODS

The examination of the above issue seemed to be reasonable through the cultivation system of the maize, because it is an important crop, it has a great sowing area (1.1 - 1.3 million ha out of the total 4.7 million ha), and the average yield has decreased in the last few years (1992: 3,70; 1993: 3,63 t/ha), partly as the result of soil conditions damages.

Objective of the examinations:

1. Soil condition demand of maize and evaluation soil condition of the yield.

2. Determining the interrelations between soil condition damages and the applied soil cultivation systems.

3. Evaluation of possibilities of changing into the adaptable soil tillage on soils with unfavourable physical condition.

For Task 1, we determined the soil condition demand according to the technical literature (Revut 1992, Sipos-Szirtes 1970, Rosenberg 1964, Birkás 1987) and the results of the model and field experiments made by the department.

In 1991-1993, the soil of total 2100 ha maize fields were examined according to its condition in 0-60 cm layer, in the area of Gödöllô, Hatvan and Marcali. The method of examination was the cartridge-sampling by Nekrasov, and section analysis with 4 repetitions in each sampling place. We also used the measuring data of the Plant and Soil Protection Service of Kaposvár.

For Task 2, the depth and method of soil tillage for four years retrospectively, the soil condition and he maize yield was examined.

Task 3 contained the suggestions on the basis of examinations.

RESULTS AND DISCUSSION

The soil condition demand of maize

The maize is developing well in the growing season on soils with 40,0-45,0 clay content, and appropriate fertile layer, provided that there is no compacted layer - that is less than 40 % total porosity - in the 0-40 cm section. We know some results which prove the necessity of good soil condition of 0-60 cm section. And the direct-drilling tolerance of maize is also well-known.

When the maize is sprouting, 48-52 % total porosity is favourable. The layer around the seed, however, should be more compacted, with 44-48 % total porosity. In case of direct drilling, the seedbed optimum is different, but more than 44 pore volume % is not desirable. Most of these data is connected to traditional tillage systems. Although they are less discussed in the recent studies (Larson 1964, Carter 1990, Horne et al 1992), we used them as the basis of comparison because of the traditional tillage aspect.

Condition of the examined soil

On the 2100 ha examined area, before flowering, the frequency of inappropriate compaction (less or more than 40 P%, or 1,55 g.cm^3 dry bulk density) in different soil layers was the following (Figure 1)

Version	*Place of compacted layers in given depth (cm)*	*Frequency (%)*
a.	10-12 and 28-32	18,42
b.	6-10 and below 40	17,71
c.	18-22 and below 40	13,25
d.	30-32	13,00
e.	6-10, 22-25 and below 40	9,31
f.	10-12, 22-25 and below 40	9,20
g.	22-25, 40-45 and below 50	8,86
h.	Did not contain compacted layer	10,25

It can be stated, that the upper layer of soils on the examined areas is usually appropriate. Close to the surface, however, the frequency of harmful compaction is 54,64% (a,b,e,f). Below 40 cm (b,c,e,f,g), 58,33 % of the total examined area is compacted. Favourable condition of soil was observed in 10,25 % of the cases (h).

Interrelations between soil condition damages and the applied tillage systems

The soil condition damages on the examined areas were the results of recent tillage errors. Loosening in order to improve the soil condition was made only on 10,25 % of the total area (h). Deep ploughing (30-32 cm), which is considered to be desirable for the maize in Hungary, was made on 62,38 % of the examined area (a,b,c,d). It did not bring, however, the expected result, because the good soil condition in the upper layer made with primary tillage, was damaged during the secondary cultivation. Thus the deep tillage lost its sense.

Medium deep ploughing (22-25 cm) was used on 27,37% of the examined area (e,f,g) in winter or in spring, on overwet soils. The harmful impact of cultivation made on too wet soil could be observed.

Former tillage errors, or the existence of tillage pan could be seen on 90 % of the examined area. Not transformed stubble residues were found in the compacted layers or below them in 58,79% of the area (a,d,e,f,g). Deformed or unabortived maize roots appeared in all the versions where compacted layers appeared close to the surface.

Evaluating the yield, it was considered that the growing period was in dry years, and the nutrient supply of the 2100 ha maize was at a national average, that means that it was deficient compared to the previous years. Anyway, it was good for a comparison. Weeds did not influence the yield. The yield results (Figure l) show that the most unfavourable conditions were resulted from the versions where compacted layers were formed close to the surface. Where the roots could grow in a suitable depth, even if not favourably, the yield was acceptable at the given place and production quality. The compacted layers in the soil strengthened the bad effects of dry weather.

Necessity of adaptable soil tillage

The results of examinations were considered valuable for the given areas. We think, however, that the tendency was more interesting - considering the financial limits of the examination. The traditional cultivation is expected to give an acceptable yield. If it does not happen, the reason is usually in other factors (lack of precipitation or manure), disregarding the soil condition.

The transition to a tillage method which is adapting to the soil condition is forced partly by the cumulated earlier tillage errors, partly by the new damages made by some elements of the traditional tillage.

Experiences of three years warn us that if the basic autumn tillage is omitted, the spring ploughing method is risky. The disk used for smoothing the ploughing can cause harmful compaction on wet soil, close to the surface. Thus the space for development is very small for the roots.

According to the new research, the shallow primary tillage in spring, when made on drier soil, is more favourable because of its less compacting impact than the deep ploughing damaged with secondary tillage (Figure 2).

CONCLUSIONS

1. The foreign soil tillage trends can provide some experiences for Hungarian conditions, encouraging us to change the attitudes and methods quickly in the present difficult economic situation.

2. The adaptable soil tillage can be regarded as the basis of adaptable crop production. Its necessity in Hungary is demonstrated through the examination of maize fields carried out in the recent years.

3. The soil condition demand of the maize can justify deeper primary tillage and careful follow-up work in the traditional tillage systems. Inappropriate tillage work can result a very unfavourable soil condition - even worse than direct drilling.

4. In Hungary, the primary tillage was delayed for spring on more than 1 million hectares in the last 3 years. The problem is not only in this fact, rather in the harmful compaction cause by the spring soil tillage. Seven versions of harmful compaction was observed on 2100 ha examined maize fields. In the given dry years, the higher production risk was caused by the compaction close to the surface (in 6-10 cm depth).

5. Close to the surface, the depth of primary tillage lost its significance because of the compaction caused by secondary tillage.

6. Under the given difficult farming conditions, the basic element of the traditional tillage - ploughing - should be substituted with another method on the damaged soils.

7. The necessity of adaptable soil tillage is justified by the present unfavourable condition of the soils and the increasing profitability. It can be a shallow tillage, or a method according to the principle which does not cause further damage to the soil.

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Figure 1. Compacted layers in the soil profile and the yield of maize on 2100 ha (1991-1993)

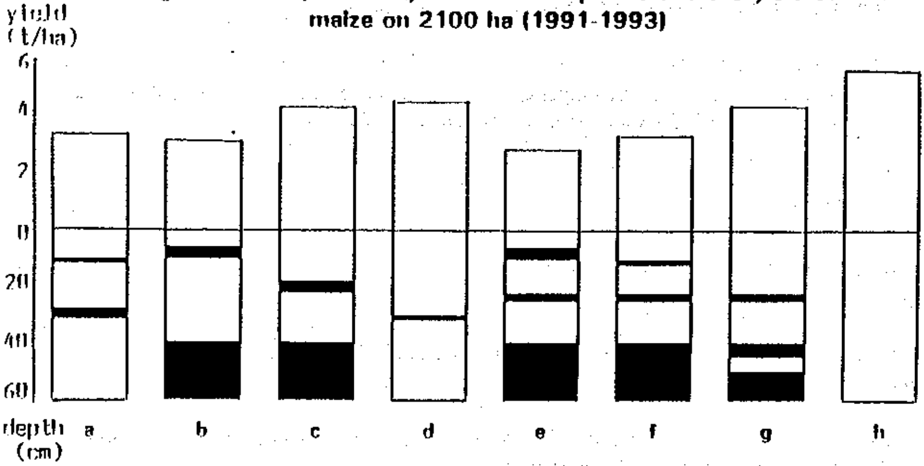
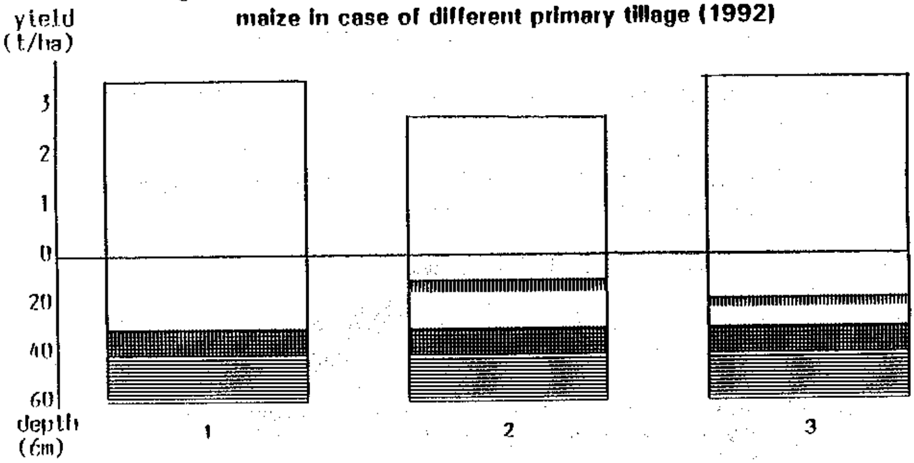


Figure 2. Compacted layers in the soil profile and the yield of maize in case of different primary tillage (1992)



MANURE TILLER FOR AGRICULTURAL SOIL IMPROVEMENT IN THE EROSION PRONE SOUTHEASTERN NIGERIA

by

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ABSTRACT

A manure tiller which is a soil tillage machine for incorporating manure and plant residue into an agricultural soil was designed and constructed in the soil tillage laboratory at the Federal University of Technology, Owerri, Nigeria. The machine consisted of a hydraulically operated subsoiler, hopper for the manure or plant residue, a shredder for size reduction of the manure, a conveyor belt, a furrow opener and furrow coverer. The machine is towed by a tractor during operation and in transportation. It also operates on the principle of minimum tillage. Thus, in an attempt to minimise the number of runs of the machine over the agricultural field, the integrated process of soil improvement through use of the machine involves continuous loosening of the soil with the subsoiler, shredding the manure or plant residue in the hopper and pushing the manure into an opened furrow in the loosened soil at the required depth in one tillage run.

A performance evaluation of the machine showed that a uniformity of coverage of the manure in the furrow in relation to the depth of the furrow varied with the speed of operation. The soil's aggregate stability showed a significant improvement with the incorporation of the manure into the soil.

INTRODUCTION

Soil used as a growing medium will often benefit from improvement. The ameliorants include bulk organic matter such as manures and composts which improve the structure and water holding capacity of the soil; inorganic fertilisers and lime which improve soil fertility; special soil conditioners which also improve soil structure. The use of bulk organic manures, composts or waste products to improve soil introduces some form of hazards to the human handlers and the environment. Often times, in the developing countries the hazards on human beings are not easily related to the application of the ameliorants because of the low level of consciousness.

Therefore, the mechanization of the process of application of the ameliorants into the soil calls for the use of simple machines that can work the materials well into the soil during cultivation (Koller, 1979). Generally, the optimum placement of the ameliorants may encourage deeper rooting of crops and minimize surface transportation of ameliorants during runoff into rural community streams or contribute to erosion control (Hyde, et al, 1984; Johnston, 1979).

The project on the development of a manure tiller is an on going university based engineering research on the improvement of the local process of incorporating manure or plant residue into the erosion prone soils in Southeastern Nigeria (Ijioma, 1990). The top soils in the agricultural fields in Southeastern Nigeria are generally thin and highly erodible. Fortunately a lot of poultry industries have recently developed in the Southeastern Nigeria. The daily problem of the poultry industry has been the regular disposal of the poultry droppings which have become attractive for agricultural soil improvement in that part of the country.

The objectives of the project which emphasize the mechanization of the handling process of manure incorporation into agricultural soils are in line with other related experiments that have been reported in the literature.

MATERIALS AND METHODS

The manure tiller which was designed and constructed in the Department of Agricultural Engineering, Federal University of Technology, Owerri, Nigeria consisted of a tractor drawn trolley carrying a hydraulically operated manure tank. The tank preceeded a primary chisel plough which opens and loosens up the furrow for the incorporation of the manure.

The tank which was developed in the form of a hopper has a metering unit at its base. The metering unit consisted of a canvas belt conveyor and an agitator to break down or pulverize the manure before being dropped into the soil. At the outlet end of the hopper were attached a secondary furrow opener and a furrow coverer which run through the already loosened soil in the furrow. The secondary furrow opener enables the manure to drop directly into the opened furrow at the required depth. The furrow coverer following the opener covers the metered manure in the furrow with loosened soil. The tank and the chisel plow are operated by the same hydraulic cylinder while the belt conveyor is driven by a system of pulleys and gear train transmissions from the rear axle of the trolley (fig.1).

The manure tiller of total dimensions 1.34x1.85m has been subjected to series of performance evaluation tests. In determining the uniformity of coverage of the manure in the furrow, the manure tiller was used in incorporating poultry manure into a reclaimed sandy loam field at the Federal University of Technology, Owerri, Nigeria. The field tests were run with the chisel plough of 3cm and 6cm widths, operated at 6cm, 12cm, 18cm and 25cm depths and at speeds of 18km/h and 36km/h. There were thus a total of 24 statistically randomized treatment combinations representing 24 treatment plots. Each plot was of the 3m width to accommodate freely the overall width of the tractor and the manure tiller. The length of each plot was 10m. The chisel plough was used at a rake angle of 20° in each treatment combination. Every other geometry of the tillage tool was held constant in all the treatment combinations.

In each test run, a weighed quantity of dried poultry droppings mixed with sawdust was loaded into the hopper before the commencement of the run on a plot. The time taken to cover a particular distance along the furrow was noted and the remaining weight of the manure in the hopper was measured. For each metre run, the depth of the furrow, the depth of manure in the furrow, the length of manure coverage and the width of the manure were measured. The measurements carried out at every one metre interval were added up for each plot.

The uniformity of depth coverage was calculated from the fractional relationship between the average depth of manure deposited along the furrow and the overall depth of the furrow. The uniformity of distance coverage was calculated from the fractional relationship between the total length distance of manure deposited along a furrow in a plot and the total length of the furrow in a plot. The two fractions were added up to make up the total uniformity of coverage for the treatment in that plot.

RESULTS AND DISCUSSION

Figure 2 shows typical measurements of depths and lengths of coverage of manure deposits along a furrow. The uniformity of coverage ranged from 0.34 to 0.46 Table 1 shows the statistical analysis of variance of the effects of depth, width and speed of the manure tiller on the uniformity of coverage in the soil. Table 2 shows the main effects. Since this paper and field tests were primarily for the purpose of evaluating the machine performance, the other agronomic tests on the benefits of incorporating manure into the soil have been reported elsewhere in another literature (Ijioma, 1990).

From the statistical analysis of the results, it was evident that the effects of blade width, speed and interaction of width with depth on the uniformity of coverage were highly significant. These results indicate further improvements in the machine output.

Table 1 ANOVA on effects of depth, width and speed of a manure tiller on the manure uniformity of coverage in the soil.

Source of variations	Degrees of freedom	Sum of squares	F Values
Total	74	0.1237	
Model	26	0.1062	11.21**
Block	2	0.0010	1.34
C versus DWS combination	1	0.0302	82.83**
Depth (D)	3	0.0019	1.78
Width (W)	2	0.0187	25.72**
D * W	6	0.0147	6.70**
Speed (S)	1	0.0317	86.92**
D * S	3	0.0007	0.68
W * S	2	0.0008	1.16
D * W * S	6	0.0064	2.94*
Error	48	0.0175	
		4.75	

** Significant at the 1 percent level
* Significant at the 5 percent level

Table 2 Main effects of blade width and speed on the uniformity of coverage.

	width		
cm	7	14	21
uniformity of coverage	0.42	0.38	0.39
0.01	a	b	b
0.05	a	b	b

	Speed of operation	
km/h	18	36
uniformity of coverage	0.38	0.42
0.01	b	a
0.05	b	a

CONCLUSION

In recognition of the agronomic improvement of soil through incorporation of manure into the soil, the machine which has been developed to handle bulk aspects of the manure has proved quite useful. Aspects of the machine that need to be modified include the removal of the four wheels so as to minimize the soil compaction effect. The advantage of the machine as it is being used is the minimal reduction in traffic and soil preparation operations involved. In one travel, the soil is primarily tilled, the furrow opened, the manure incorporated and properly covered for effective decaying. This soil improvement approach contributes to soil and water conservation and erosion control.

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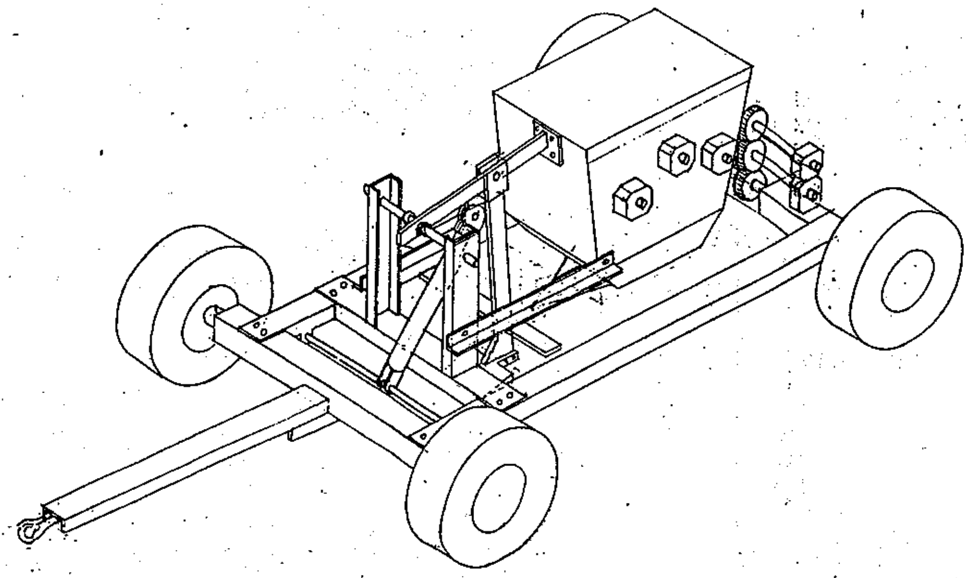

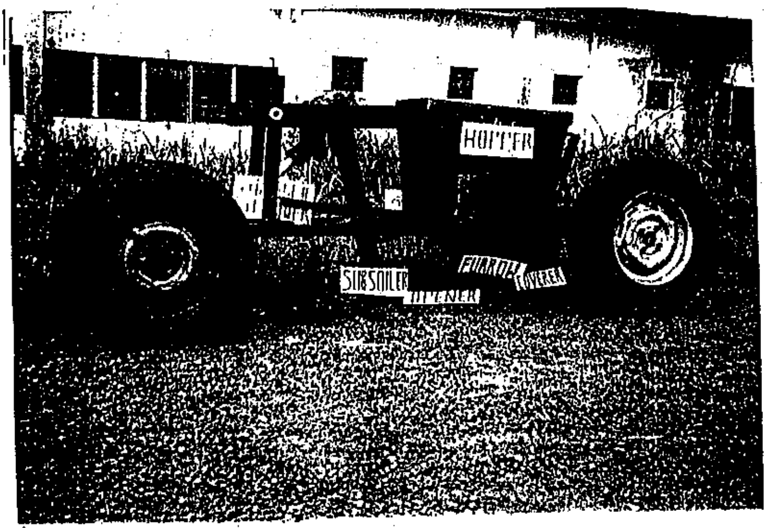

Fig. 1. Manure tiller in pictorial view as designed above and as constructed below.

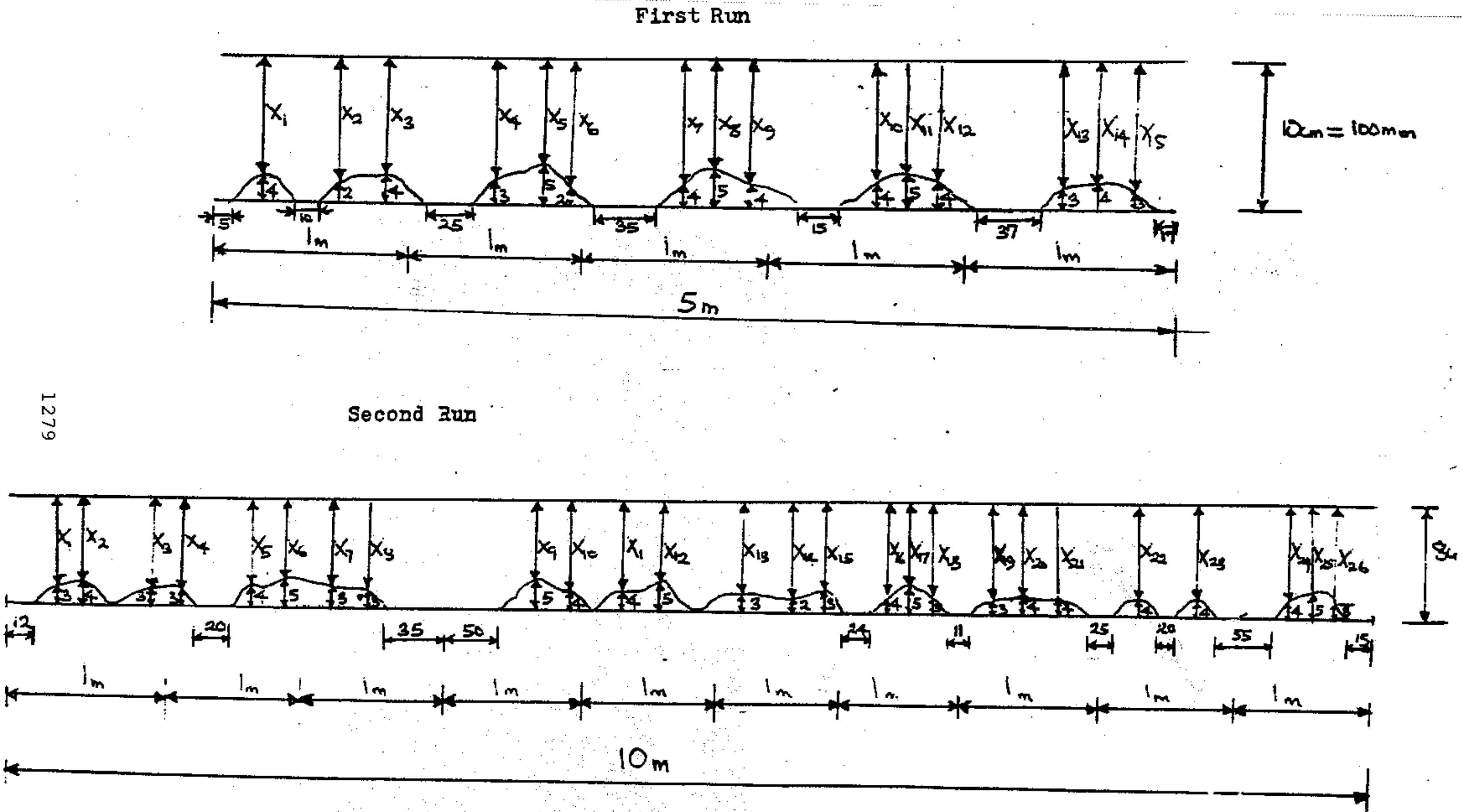

Fig.2. Typical measurements of depths and lengths of coverage of manure deposits along a furrow.

SELECTION OF TILLAGE TOOL PARAMETERS

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STATE OF THE PROBLEM

Separation of agrarian sciences into some narrower ones (soil science, farming, mechanization of agriculture) resulted in breaking-off of mutual understanding between speialists dealing with the same problem, i.e. soil, tillage, plant-growing, etc. This isolation is particularly harmful for designing agricultural machinery.

Contradictions between interests of manufacturers in power-intensive agricultural machinery and capacity of soil to resist technogenic effects were displayed distinctly in overcompaction of the plough layer and soil pan and increase of soil erosion. For development of zonal and microzonal systems technologies of tillage and zonal tillage tools a new idea is required which would integrated the latest achievements and know-hows of such branches of agrarian sciences as soil science, farming, plant-growing, meteorology with methods of tillage mechanics.

Different models of optimum structure of plough layer correspond to different climatic conditions. However tillage quality depends on moisture content of soil (Fig. 1). Furthermore, different tools show different effect in soil of the same moisture content (Fig. 2). For most researchers these features are negligible and those "skilful" ones can "prove" sometimes advantages of poor tillage tools.

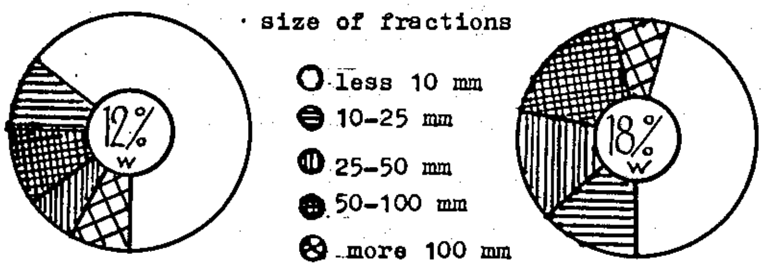

Fig. 1. Influence of soil moisture content on quality of tillage

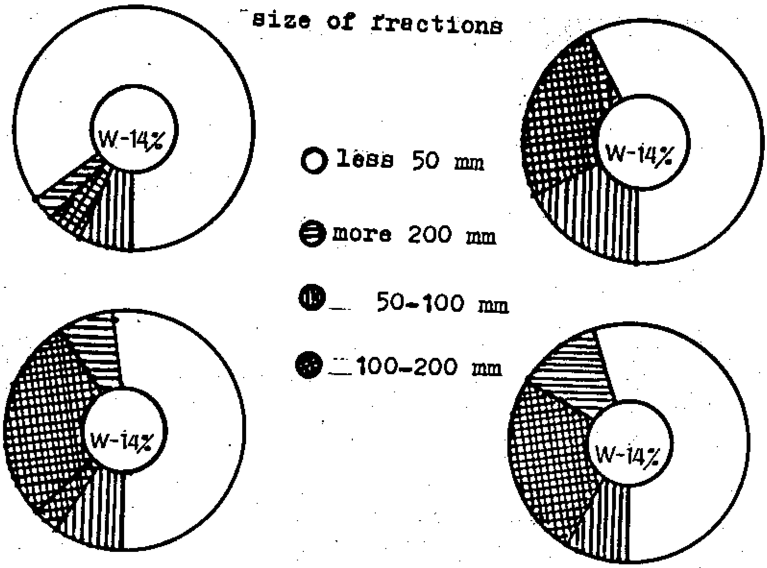

Fig. 2. Quality of tillage by different tools

The main principle of our ideas is development of optimum models for structure of the plough layer.

OPTIMIZATION OF PHYSICAL FEATURES OF SOIL IN PLOUGH LAYER

Analysis of meteorological data for many years including data of moisture content of the plough layer makes it possible to analyse a range of climatic conditions into 3-5 groups. Later, climate is simulated for one or another group with different plough layer structure. Because of a great deal of factors affecting results of experiments, the plant is the main object for study using crop yield as parameter.

Experiments on microplots resulted in mathematic models for a group of meteorological conditions

$$Qk = f_k (y_i) \qquad (1)$$

where y_i = parameters of the plough layer, density of a layer, aggregate composition, and Qk = yields on microplots at "k" - meteorologic condition.

Optimizing Eq. 1, we can calculate parameters of the plough layer composition y_i^{opt} that provide the largest crop yield in the year of adequate meteorological conditions.

Requirements for optimum structure of plough layer can be specified in three ways:

Firstly: the purpose is to obtain the highest yield on average for many years;

Secondly: the purpose is to obtain the highest yield in unfavourable climatic conditions (drought in the south of Ukraine);

Thirdly: the purpose is to obtain the highest yield next year (for winter crops) or this year (for spring crops) according to the weather forecast for the next year.

TECHNOLOGICAL ESTIMATION OF TILLAGE TOOLS AND IMPLEMENTS

Technological estimation of tillage tools and technologies is based on:

- structure of plough layer in view of its possible state;
- parameters that define unambiguosly geometry and kinetics of a tillage tool (x_j);
- model of optimum structure of plough layer.

The following problems are solved:

1. Parameters that define unambiguosly geometry and kinetics of a tillage tool are calculated.
2. By multifactor designing of experiments a number and geometries of pilot tillage tools-identifiers are defined.
3. Identifiers are manufactured.
4. In each group, a soil-climate condition technological experiment is carried out and regression equations are derived on the results of these experiments:

$$y_i = f\,(x_j)$$

where y_i = parameters that define structure of the plough layer. If $i = j$, then a closed system of algebraic equations can be obtained. After substitution of y_i^{opt} instead of y_i in the left part of the equation and solution of the system (3) with respect of x_j unknowns we obtain parameters of a tillage tool that provide optimum composition of the plough layer for the given soil-climate conditions. If the solution of the equation not all roots valid, it is impossible to obtain optimum structure of plough layer by this tillage tool, however we change its geometry.

For this occasion potential technological estimation of the tillage tool is given, i.e. its limiting potentialities above those no changes of parameters will improve quality of tillage. In this case we estimate the highest possible yield provided by tillage of the highest quality by the given type of tillage tool.

We introduce a notion "technological potentiality of the given type of soil tillage" (the given tillage technology) as a ratio

$$\eta = \frac{\tilde{Q}max}{Qmax}$$

where $\tilde{Q}max$ = the highest possible yield provided by the given type of the tillage tool (tillage techonogy) according to the quality of soil preparation; and Qmax = the highest yield gathered in when physical features of soil are optimized.

In the same way we recommend to estimate tillage technologies but parameters of tillage quality are calculated only after the final step, i.e. soil preparation.

During technological experiments we also determine influence of parameters of geometry and kinetics of tillage tools on energetics (F): $F = f\,(x_i)$.

OPTIMIZATION METHODS OF TILLAGE TOOLS PARAMETERS

Regression equations of optimization of physical features of plough layer for influence of parameters (geometry and kinetics) of tillage tools on qualitative structure of plough layer and energy consumption makes it possible to calculate optimum parameters of a tillage tool.

After the experiment we put mean data into equations

$$\Delta Q = Q_{max} - Q_i \rightarrow \min;$$
$$\Delta F = F_{min} - F \rightarrow \min;$$
$$Q = f_1(y_i);$$
$$F = f_2(x_j);$$
$$y_i = f_3(x_j).$$

Solution of the given system by a computer allows to find optimum parameters of tillage tools based on such an optimization parameters as "crop yield" according to soil and weather conditions.

AN EXAMPLE OF THE METHOD

For illustration consider a problem of calculation of tillage tool parameters for subsurface tillage for barley.

According to the results of the experiments on microplots a regression equation of barley yield was derived according to the structure, composition and density of soil.

$$Q = 169.23 + 6.39Y_1 + 17.40Y_2 + 3.12Y_3 - 2.37Y_4 + 9.64Y_1Y_2 + 7.08Y_1Y_3 + 18.08Y_1Y_4 - 22.25Y_2Y_4 - 9.13Y_3Y_4 - 26.59Y_1^2 + 24.81Y_2^2 - 54Y_3^2 - 19.60Y_4^2,$$

where Y_1 - percentage of 5-20 mm size fraction in 0-4 cm layer;
Y_2 - percentage of 0.25-5 mm size fraction in 4-8 cm layer;
Y_3 - percentage of 1-50 mm size faction in 8-18 cm layer;
Y_4 - soil density in 8-18 cm layer;
- barley yield.

Q_{max} = 2.15 t at Y_1^{opt} = 0.18 (54.5%), Y_2^{opt} = 1.00 (80%), or Y_3^{opt} = 0.015 (60.4%), Y_4^{opt} = 0.229 (1.22 g/cm^3).

The problem is calculation of parameters of a plane cutting tool at the same conditions. All alternative designs that show solid surface of the tillage tool can be calculated by four parameters (X_1, X_2, X_3, X_4) (Fig. 3).

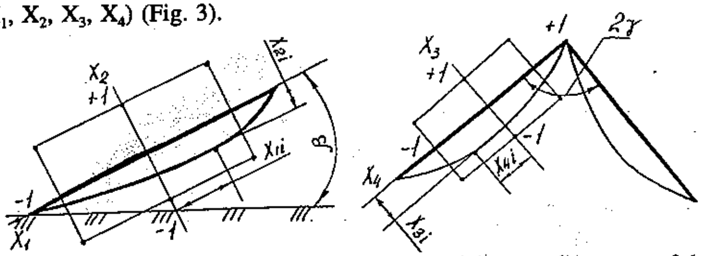

Fig. 3. Factors determining side curved surface of the claw

Factors determining rounding curve of the cutting edge of working member in horizontal plane

When the matrix of the experiment was plotted, fifteen tillage tools-identifiers were manufactured (Fig. 4).

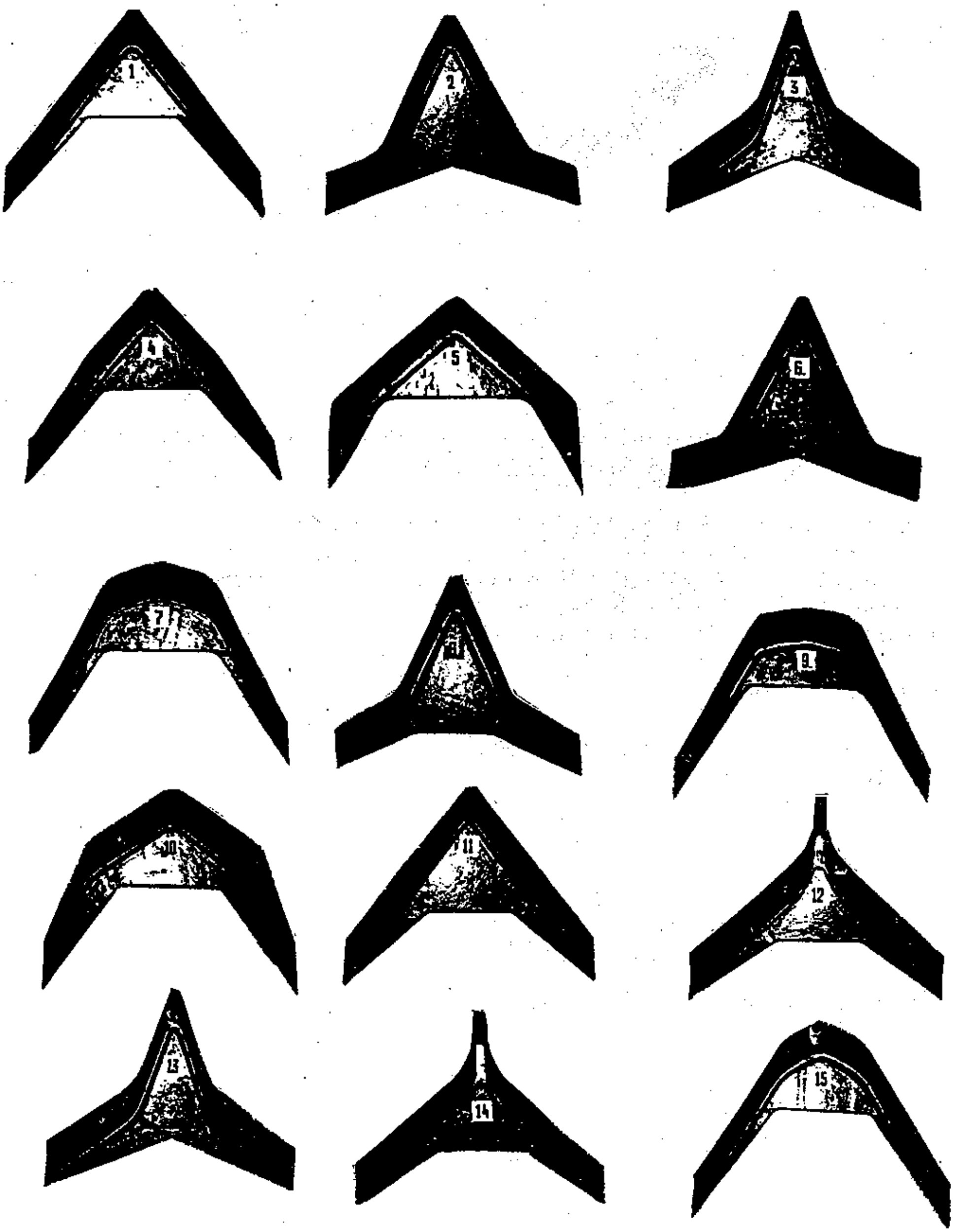

Fig. 4. Samples of identificator working tools based on mathematical planning of experiments.

Determination of Y_1, Y_2, Y_3, Y_4 of aggregate composition and soil density after pass of identifiers as well as draught resistance (F) were included in the research programme. According to operation of tillage tools we calculate optimization parameter for them that can be individual (Y_j) or complex (Y_i - Y_n) provided that $j = i$.

In this case Y_3^n - percentage of 1-50 mm size fraction in 8-18 cm layer is chosen to be an optimization parameter.

$$Y_3 = 40.44 + 1.11X_1 - 4.49X_2 - 2.67X_3 + 47X_4 + 4.05\,X_1X_2 + 9.87X_1X_3 + 0.89X_1X_4 + 5.97X_2X_3 - 3.85X_3X_4 - 4.06X_1^2 + 1.4X_2^2 - 2.01X_3^2 + 11.66X_4^2.$$

Simultaneously draught resistance of the tillage tool at corresponding parameters is:

$$F = 282.1 - 13.13X_1 + 18.2X_2 - 15.02X_3 + 10.78X_4 - 12.51X_1X_2 - 10.89X_2X_4 - 43.4X_3X_4\ 26.78X_1^2 + 38.10X_3^2 - 26.86X_4^2.$$

For optimum parameters of a tillage tool this condition must be satisfied:

$$Q_{max} - Q = \Delta Q \rightarrow \min$$
$$F_{min} - F = \Delta F \rightarrow \min.$$

When computing, more acceptable values of tillage parameters with minimum ΔQ and ΔF were chosen by a search method of possible combination.

Optimization of parameters of tillage tools in this case resulted in:

$$X_1 = 1.0;\ X_2 = -0.8;\ X_3 = -0.4;\ X_4 = -1.0$$

in case of shortage of yields $\Delta Q = 0.66\%$ and increase of draught resistance $\Delta F = 4.28\%$ in comparison with optimum. According to the parameters of new tillage tool was designed and tested by comparison with comerical tools manufactured in the countries of the former USSR.

Results are as follows:

according to criterium Y_3 (a numher of 1-50 mm size factions in 8-18 cm layer):

for a pilot tillage tool:

$$Y_3 = 69.00 + 4.17\widetilde{X}_1 - 7.15\widetilde{X}_2 - 1.47\widetilde{X}_1^2 - 0.28\widetilde{X}_2^2$$
$$(Y_{3min} = 57.3\%;\ Y_{3max} = 80.2\%)$$

for comercial tool:

$$Y_3 = 58.73 + 5.22\widetilde{X}_1 - 4.82\widetilde{X}_2 + 0.59\widetilde{X}_1^2 + 0.98\widetilde{X}_2^2$$
$$(Y_{3min} = 52.3\%;\ Y_{3max} = 72.4\%)$$

where $\widetilde{X}_1$ - speed of the machine, km/h;
$\widetilde{X}_2$ - depth of tillage (up to 16 cm).

According to the draught resistance:

for a pilot tool as coded

$$Z = 18.86 + 1.22\widetilde{X}_1 + 5.39\widetilde{X}_2 + 1.35\widetilde{X}_1^2 + 0.86\widetilde{X}_1^2$$
$$(F_{max} = 17.11\text{ kH};\ F_{min} = 8.63\text{ kH});$$

for commercial:

$$Z = 20.65 + 2.76\widetilde{X}_1 + 7.68\widetilde{X}_2 + 0.89\widetilde{X}_1^2 + 2.53\widetilde{X}_2^2$$
$$(F_{max} = 23.18\text{ kH};\ F_{min} = 9.86\text{ kH}).$$

The strength of our idea lies in the fact that for research in each zone we need no design of a new pilot tillage tool by intuition. We should research only standard tools-identifiers. At the same time for each type of tillage tool we need a set of tools-identifiers like litmus-paper in chemistry so that to calculate parameters of the given tillage tool in any soil-climate conditions.

An approach to unification of models of optimum plough layer, to connection of tool parameters with a structure of plough layer and power consumption has been taken. Connection of "soil - tillage tool parameters - tillage quality - crop yield - power consumption" in the system of regression equations has been revealed.

ASSESSEMENT OF SOIL CHANGES WITH NO-TILL PLANTER OPTIONS IN CORN PRODUCTION

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ABSTRACT

A four year study was conducted on medium-textured soils to examine the effect of no-till planter modifications on soil properties and crop response. Corn was planted following previous crops of grain corn and winter wheat with seedbeds prepared by moldboard tillage or various soil loosening and row cleaning devices mounted directly on a no-till row crop planter. Disc row cleaners greatly reduced in-row residue cover compared to fluted coulters when following winter wheat. Water run-off volumes from a simulated rainfall event were significantly higher, but soil loss was similar, following disc row cleaners compared to other no-till planter attachments. Disc row cleaners often resulted in significant increases in soil penetrometer resistance at depths of 4.5 - 9.0 cm in the row zone. Although no-till corn yields averaged 12% lower than those after moldboard tillage, differences in soil physical conditions resulting from various no-till planter attachments had no consistent effect on final corn yields. Future tillage system comparisons should acknowledge the range of soil physical properties possible within a no-till system even when the same basic planter is used.

INTRODUCTION

High amounts of soil erosion associated with moldboard plowing coupled with recent success in Ontario of no-till systems for corn (*Zea mays* L.) following crops such as soybeans (*Glycine max* L.) (1) and alfalfa (*Medicago sativa* L.) (2) have encouraged some corn producers to switch to no-till. No-till production of corn, however, has been less successful following crops of corn or winter wheat (*Triticum aestivum* L.) which produce higher amounts of more persistent surface residues. Previous U.S. research (3) has attributed slower rates of corn development in tillage systems that left high amounts of in-row residue cover to reduced in-row soil temperature.

Utilizing planter attachments such as row clearing discs or coulters to reduce the amount of in-row residue cover may eliminate yield reductions associated with no-till planting into high amounts of surface placed residue. Voroney *et al.* (4) reported that clearing spring barley (*Hordeum vulgare* L.) interseeded with red clover (*Trifolium pratense* L.) residue from the row area during corn planting increased in-row soil temperature, early season growth rate and grain yield. Strip or zone tillage studies for monoculture corn production have reported that no-till corn yields were occasionally increased by planting corn into narrow tilled zones (5).

A series of field studies were conducted following previous crops of grain corn and winter wheat interseeded with red clover to evaluate the effect of moldboard plowing and various no-till planting options on soil physical conditions, soil erosion potential during the post planting period and corn growth and yield.

MATERIALS AND METHODS

The field trials were conducted on silt loam (medium, mixed, weakly to moderately calcareous Typic Hapludalf) soils in central southern Ontario near Elora (1990 to 1992) and Woodstock (1991 to 1993). Corn followed previous crops of either winter wheat (underseeded to red clover) or grain corn. Where corn followed a previous crop of winter wheat and red clover, the red clover was established by broadcast seeding into winter wheat. Red clover was allowed to regrow the following spring until 1- to 2-wk prior to corn planting when it was chemically controlled.

The experiments were arranged in randomized complete blocks with 4 replications with the following treatments:

1. **Moldboard plowing (Plow)** - the seedbed was prepared by moldboard plowing 15 cm deep 1- to 2-wk prior to corn planting followed by secondary tillage which occurred just prior to corn planting.
2. **Slot-till (Slot)** - corn was planted with minimal in-row soil or residue disturbance.
3. **Disc row cleaners (Disc-1)** - prior to seed placement, a 7- to 10- cm band of residue was cleared from the row area using a single set of disc row cleaners mounted on a gauge wheel assembly that was attached to the planter fertilizer tool bar.
4. **Disc row cleaners (Disc-2)** - a 15- to 18- cm band of residue was cleared from the row area by mounting a second set of disc row cleaners on the seeding units of the planter in conjunction with the discs described in treatment 3.
5. **Spoked row cleaners (Spokes)** - prior to seed placement, a 7- to 10- cm band of residue was cleared from the row area using a single set of spoked disc row cleaners mounted on the seeding units of the planter.
6. **Zone tillage (Zone-2)** - in-row soil was loosened prior to seed placement using two fluted coulters (2.5 cm amplitude) operating at a depth of 7.5 cm. The coulters were positioned 7 cm on either side of the row.
7. **Zone tillage (Zone-3)** - two fluted coulters operating at a depth of 7.5 cm were positioned 10 cm on either side of the row. A third fluted coulter (1.25 cm amplitude) was positioned directly in-line with the seed openers.

In-row residue cover was determined using the line transect method (6) by placing a rope with 50 markings diagonally over the row within 10 cm of row centre. In-row penetrometer resistance, and soil erosion potential measurements were conducted only in the Plow, Slot, Disc-2 and Zone-2 treatments. Penetrometer resistance was determined 2- to 3-wk following planting in 1991 and 1992 using a Rimik hand-held recording penetrometer (Toowoomba, Australia).

Simulated rainfall events were conducted 6- to 8-wk following planting to evaluate planting options for their potential for water run-off and soil erosion during the post planting period using a Guelph Rainfall Simulator II (7). Rainfall intensity of the simulated storm was 19 cm/hour and lasted for 10 minutes. Parameters measured during the rainfall simulation were residue cover, volume of surface water run-off, and soil loss; all three parameters were based upon a sample quadrant that was 1 m by 1 m, centred on two rows.

RESULTS AND DISCUSSION

In-row residue cover

In-row residue cover 2- to 3-wk after planting was generally much higher for the slot tillage system following winter wheat than following corn (Table 1). Residue was effectively reduced by both coulters and row clearing discs following both previous crops. However, row clearing discs reduced the amount of in-row residue cover to a greater extent than coulters; especially when the previous crop was winter wheat. Adding a third coulter generally reduced the amount of in-row residue cover. Adding a second set of row clearing discs tended to widen the actual zone of residue clearing following both crops but reduced the residue level only following corn. This is probably due to the fact that corn residues were more prone to being returned to the row area by wind and rain unless cleared from a wider area as in the case of the Disc-2 treatment. It should be noted that no treatments within the study involved hand clearing or placing of residues, nor were any of the mechanical devices augmented in any way to maintain a residue free zone during the course of the growing season.

Table 1 The effect of moldboard plowing and various no-till planting options on percent in-row residue cover 2- to 3-wk after planting.

Tillage System	Previous Crop+ Wheat	Corn
	%	
Moldboard	9 e++	11 g
Slot	72 a	47 a
Disc-1	26 d	31 de
Disc-2	28 d	21 f
Spoke	-	32 cde
Zone-2	61 b	46 ab
Zone-3	50 c	39 bc

\+ Values presented are means of Elora (1990-1992) for wheat as the previous crop and Elora and Woodstock (1991-1993) for corn as the previous crop.

++ Within column means followed by the same letter are not different according to a protected LSD test at the 5% level of probability.

Potential for soil erosion

An intense simulated rainfall event was utilized to assess the potential for surface water run-off and soil loss during the post planting period. Residue cover, surface water run-off and soil loss values are illustrated in Figure 1 and include results only from tests where corn followed winter wheat. Values are combined over years since there was no evidence of a year by planting option interaction. Similar results were obtained when corn was the previous crop (data not shown). When compared to any of the no-till planting options, moldboard plowing was associated with greater surface water run-off volumes and soil loss amounts. Using coulters in an attempt to improve in-row no-till seedbed conditions did not

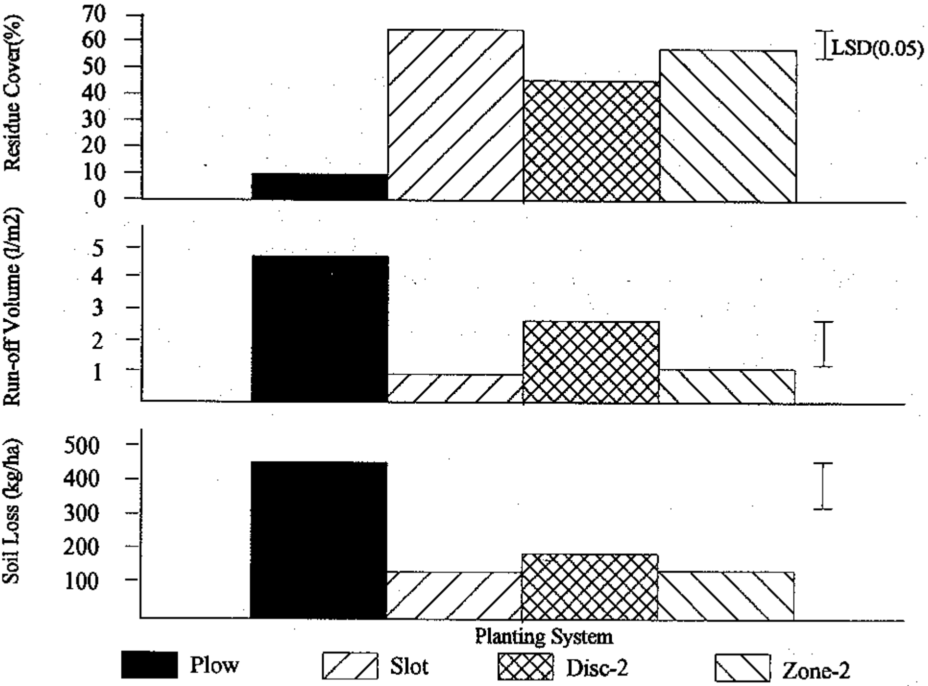

Figure 1. The effect of planting system on residue cover, run-off volume and soil loss during simulated rainfall events. Previous crop was winter wheat (Elora, 1991 + 1992)

affect the amount of soil loss or water run-off when compared to where corn had been planted with minimal in-row soil or residue disturbance. However, clearing residue from the row area using disc row cleaners almost tripled the volume of run-off compared to the other no-till planting options. Although surface water run-off volume was increased when disc row cleaners were utilized to clear residue, soil loss was only marginally increased.

Penetrometer resistance

Utilization of disc row cleaners to clear in-row residue was associated with corn being planted into a more consolidated seed zone area. Among the no-till planting options, using disc row cleaners to clear wheat/red clover or corn residues was associated with greater in-row soil resistance in the 5- to 9- cm depth interval. When spoked disc row cleaners were employed to move corn residue out of the row area penetrometer resistances were more similar to those obtained with Slot or Zone tillage systems (Figure 2). Increased penetrometer resistances measured under Disc-2 treatments was associated with the unavoidable removal of surface soil (approximately 1.5- to 2.5- cm) by the discs in order to clear the residue and perhaps by some compactive forces of the discs. Volumetric soil moisture readings (data not shown) performed on the day of penetrometer resistance readings indicated that resistance differences among the various planting options were not the result of soil moisture differences.

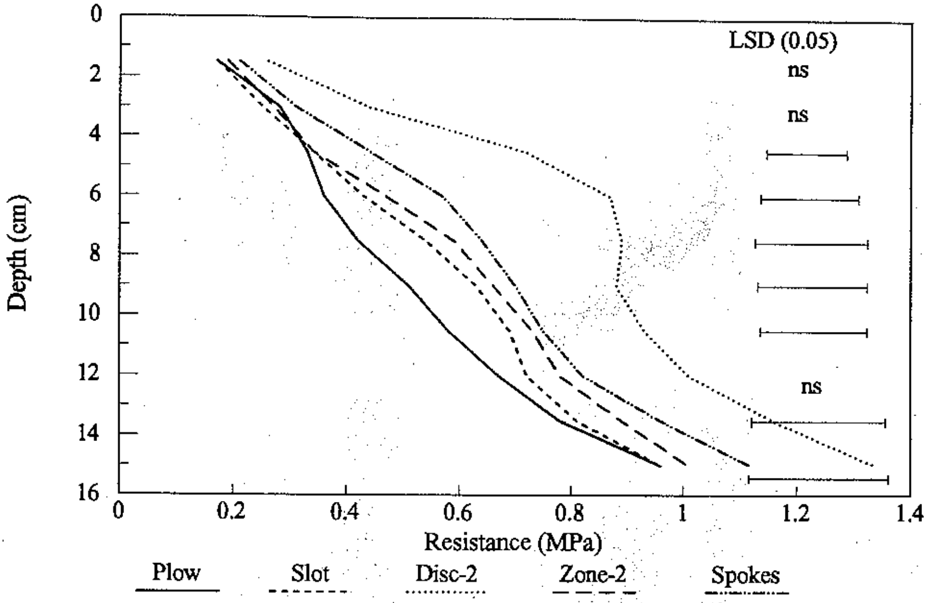

Figure 2. The effect of planting system on in-row penetrometer resistance 3 weeks after planting. Previous crop was corn (Elora, 1992).

Corn growth and yield

At all sites, moldboard plowing prior to corn planting consistently increased the rate of early season growth when compared to any of the no-till planting options (Figure 3). Modifying the no-till system by employing either row clearing discs or coulters to reduce the amount of in-row residue cover or loosen soil did not consistently affect early season corn growth rates. This lag in early growth with no-till did not consistently translate into reductions in final corn grain yield. Figure 3 illustrates that in 1991 (a year of above average growing season temperatures) yields were similar among all planting systems while in 1992 (a year of below normal growing season temperatures) yields for any of the no-till sytems were significantly lower than those obtained with moldboard plowing. Perhaps some of the corn growth enhancement which might be expected from residue clearing was confounded by greater soil strengths in the row zone.

CONCLUSIONS

1. Residue clearing devices may result in seeds being planted in row zones with significantly higher soil penetrometer resistance. No-till producers are advised that potential advantages from residue removal may be eliminated if devices cause in-row soil to be compacted or moved out of the row area. Spoked wheels may be preferable to disc units.
2. Protection from potential soil erosion was significantly increased by all no-till systems compared to moldboard plowing. Modifications to the row zone within no-till systems did not have a significant effect on soil loss potential.
3. Planter modifications which significantly altered residue cover and soil strength could not overcome the corn yield reduction associated with no-till, relative to plowing, in years with cooler growing seasons.

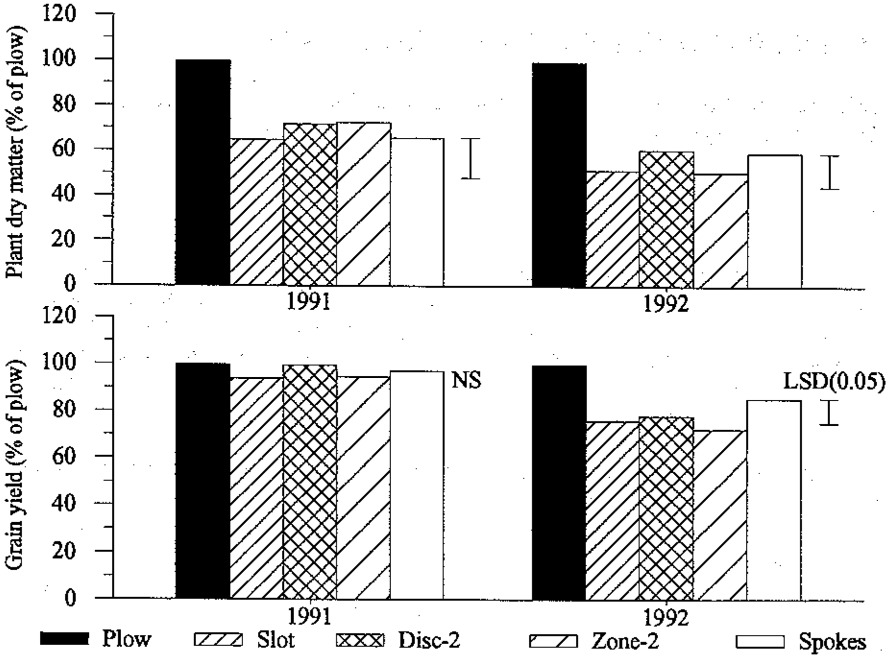

Figure 3. The effect of planting system on early season (June) dry matter and final grain corn yield. Previous crop was corn (Elora and Woodstock combined).

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HIGH SPEED PLOUGHING: A PRACTICAL REALITY

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ABSTRACT

Despite the enduring popularity of the mouldboard plough attempts to increase the speed of operation beyond 7 - 8 km h^{-1} lead to deteriorating quality of work and increased draught requirement. Increased timeliness constraints associated with autumn cultivations have necessitated larger machines in order to achieve higher work rates. This paper describes the design, construction and testing of a plough designed to operate at 12 km h^{-1} which is offered as an alternative to the mouldboard plough.

During testing the speed of 12 km h^{-1} was consistently achieved giving a 3 furrow unit a spot work rate of 1.2 ha h^{-1}. If 80 per cent field efficiency is achieved then an output of 1 ha h^{-1} is achievable in practical terms. A further 4 furrow machine of improved design has been built and tested.

INTRODUCTION

The mouldboard plough is the most popular straw incorporation tools in the UK. Its one major advantage is its almost complete burial of trash. It is generally slower than other forms of primary tillage and rather than mixing the straw it is buried in a layer some 200 - 300 mm below the soil surface. While this may work well in favourable conditions problems can be encountered where weather delays make early ploughing impossible. Ploughing in wet conditions can leave a mat of straw above a smeared layer of soil, anaerobic conditions can develop which will prevent straw breakdown and allow microbial toxins to build up which in turn can reduce the yield of the subsequent crop. In the North of England and Scotland speed is critical in order to start the straw breakdown processes as soil temperatures drop quickly in the autumn, thus the rate of straw decomposition is again slowed.

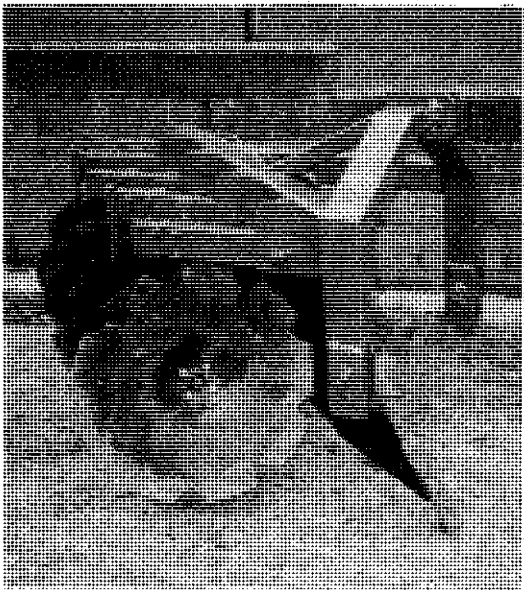
The mouldboard plough was originally designed to be used over the winter to allow natural weathering processes to take place, assisting the farmer in tillage. The situation is now changing, almost all arable combinable crops in the UK are winter sown, mainly in the period late August to late October. As a result of this some of the natural advantages of using the plough are no longer valid. The open condition of the soil after ploughing leaves the surface vulnerable to undesirable and excessive moisture loss.

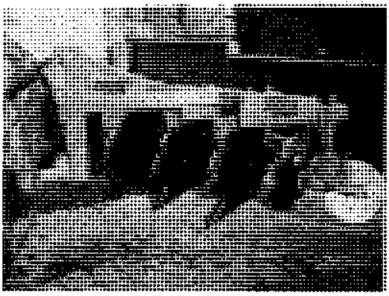
Under most soil conditions it is usual for a draught implement's power requirement to increase rapidly above an operating speed of 6 km h^{-1}. The mouldboard plough suffers more than most. This problem was illustrated by O'Callaghan and McCoy[01] when they examined the behaviour of soil over general purpose mouldboards. They were able to examine, mouldboard friction, mouldboard adhesion, acceleration of the furrow slice,lifting of furrow slice, friction on the landside and friction on the base. They suggest a four fold increase in the total draught force of the mouldboard between an operating speed of 3.2 and 12.8 km h^{-1}. The largest components of that force were mouldboard friction, 34%, acceleration of the furrow slice, 27%, while landside friction was 20%. When friction on the base is included, the draught requirement to overcome friction was 67% of the total energy input. The work was not soil specific. Clearly if ways can be found to reduce this then considerable savings in energy may be available.

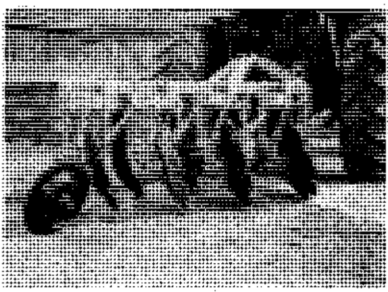
MATERIALS AND METHODS

The design selected for the high speed plough included both a rigid tine and 710 mm disc to form one furrow unit. The disc was mounted behind the tine, slightly offset from the centreline of the tine. A heavy tine was used at a rake angle of 60°. This abrupt angle meant that the tine would disrupt a larger volume of soil, although it resulted in a higher draught requirement. Below 60° and the rate of increase in draught is not matched by a corresponding increase in the volume of disturbed soil. The reasoning behind this idea was to allow soil to be brought up and cover the straw on the surface, previous experience had shown that it was more difficult to incorporate straw with discs while it remained on the surface. Initial mixing by the tine allowed the discs to perform a more thorough mixing job. The soil was also loosened and shattered by the tine allowing easier movement over the disc.

The discs were mounted on a beam behind the tine and each furrow unit was protected by a shearbolt. The point of rotation was at the front of the beam allowing the unit to move clear of any obstruction. In field trials this arrangement worked well although a more practical solution would be some form of automatically reset breakback device or hydraulic accumulator. The first version of the plough was tested by Scott [02]. It was field tested and although successful in terms of its cultivating effect a number of design shortcomings were evident. Roddy [03] redesigned the plough, in particular bringing the design up to a more commercially acceptable standard. The beam arrangement was simplified and strengthened. Further field trials were carried out in 1993 and early 1994. The mark two version of the plough is illustrated in Figure 1 below.







Calculation of Soil Forces and Draught Requirement

Draught force requirement for each tine

In addition to field testing, the theoretical performance was calculated. This was done by using standard methods for both the draught force requirement for tines and discs and a machine performance chart was calculated using soil parameters from the Nafferton Farm test site. Equation (1), based on a method for calculating the frictional component of soil resistance described by Hettiaratchi and Reece [04] was used in order to calculate the draft requirement for the tines:

$$P = \gamma z^2 K_\gamma + czK_{ca} + qzK_q \tag{1}$$

where:

where:	Depth	$z = 150$ mm
	Bulk unit weight	$\gamma = 12.0$ kN m^{-3}
	Cohesion	$c = 10$ kN m^{-2}
	Surcharge	$q = 4.5$ kN m^{-2}

In order to calculate K_γ, K_{ca} and K_q, chart values are used based on the following information:

Angle of soil-metal friction	$\delta = 24°$
Rake angle	$\alpha = 30°$
Angle of internal friction	$\phi = 30°$
Width	$B = 0.1$ m
Adhesive force	$a = 3$ kN m^{-2}
Roughness ratio	$\delta/\phi = 24 / 30 = 0.8$

K	δ	ϕ	Interpolations	
K_γ	$\delta = 0$	0.95		
	$\delta = \phi$	1.8		
	$\delta = 24°$		$0.95(1.8 / 0.95)^{0.8}$	$= 1.58$
K_{ca}	$\delta = 0$	1.4		
	$\delta = \phi$	4.0		
	$\delta = 24°$		$1.4\ (4.0 / 1.4)^{0.8}$	$= 3.24$
K_q	$\delta = 0$	1.9		
	$\delta = \phi$	3.7		
	$\delta = 24°$		$1.9(3.7 / 1.9)^{0.8}$	$= 3.24$

For data provided $P = 7.47$ kN m^{-1}

Length of the blade $= 0.15/ \sin 60°$ $= 0.173$ m

Adhesive force $=$ length * width * a $= 0.052$ kN $= A$

Soil resistance at full width of blade $= 7.47 * 0.1 = 0.747$ kN

Draught force $F_y = 0.747 \sin 54° + 0.0052 \cos 30° = 0.649$ kN

Draught force for 4 tines $F_{yt} = 2.596$ kN

Draught force requirement for discs

Alam [05] developed a mathematical model for predicting the performance of agricultural discs. It can accommodate disc having both inclination and disc angles. The method follows the technique used by Godwin et al [06] , where both disc geometry and soil properties are known, the model can predict the quasi-static soil reactions on disc implements. In order for the complex situation to be simplified so as to make the method available for practical use a number of disc performance charts were developed.

Using the method developed by Alam the performance of the disc component of the high speed plough was calculated. Known disc and soil properties were used.

Disc properties:

Disc sphere radius (R)	700 mm
Disc characteristic ratio (a/R)	0.866 m
Depth of cut (z)	150 mm
Disc angle (β)	45°
Disc inclination angle (α)	15°

Soil properties not previously expressed:

Surcharge (q)	4.5 kPa

Alam calculated disc performance charts in order that empirical correction techniques could be used. For the situation described in this study the following K-factors were calculated; where subscripts x,y, and z refer to the longitudinal plane, lateral plane and vertical plane. Further g,c and q refer to acceleration due to gravity, cohesion and surcharge.

K_{gx}	K_{cx}	K_{qx}	K_{gy}	K_{cy}	K_{qy}	K_{gz}	K_{cz}	K_{qz}
0.489	1.221	1.048	0.263	0.991	0.856	-0.321	0.157	0.064

In operation the setting of the disc implement is a function of the disc angle (β), inclination angle(α) and the depth of cut (z). The effective width of cut of a disc is given by:

$$W = \frac{2\cos\beta}{\cos\alpha}\sqrt{z(D\cos\alpha - z)} = 0.411m \tag{2}$$

where D = the diameter of the disc = 0.7 m.

Draught force component are produced for each axis, P_x = 1.097 kN, P_y = 0.877 kN and P_z = 0.078 kN. The resultant force on each disc can be determined as:

$$P = \sqrt{P_x^2 + P_y^2 + P_z^2} \tag{3}$$

$$= 1.4 \text{ kN}$$

These figures along with the calculation of tine forces can be used to calculate the draught force requirement of the machine. As with the plough speed of operation has a significant effect on the draught power requirement. A dynamic correction factor was used to calculate the draught at higher speeds.

$$D\,(V / V_0)^2$$

where V_0 was assumed to be = 4 km h^{-1}.

RESULTS AND CONCLUSIONS

Figure 2 indicates the performance of the four furrow test plough at the Nafferton site along with standard soil types to indicate the machines likely performance under those conditions. In the latest Nafferton field test (28th January 1994) an average speed of only 7.29 km h^{-1} was achieved. This was due to high soil moisture and compaction. It was felt however that the theoretical analysis gave a very good indication of the actual power requirements. The tractor used was a MF3090, 75 kW. The same tractor along with a smaller Zetor 7211 model had been used in earlier trials at Styford, Northumberland on sandy loam where the machine had performed well and at a constant speed of 12 km h^{-1}.

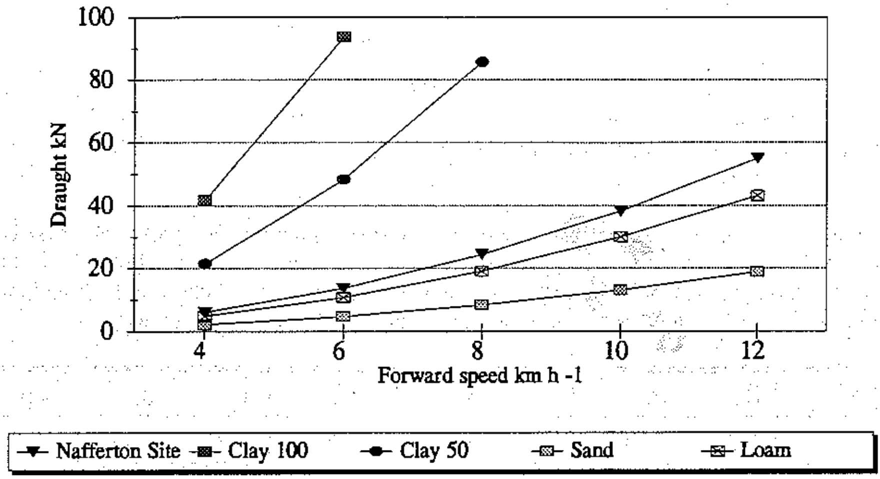


Figure 2. Machine performance chart
Based on a method from Alam(1989)

In addition to the draught power requirement other aspects of the machines performance were measured. Using a surface micro relief meter developed by Wigglesworth [07] the standard deviation of the surface profile was measured. The relief meter measures the elevation of 400 points per square meter. The standard deviation gives a measure of the relative unevenness of the soil surface. In trials in sandy loam the machine performed slightly better than the mouldboard plough, whereas in the winter trials at Nafferton the standard deviation was greater than that for the mouldboard plough.

One of the major problems of possible alternatives to the plough is insufficient trash burial. Figure 3 gives a visual impression of the machines performance under conditions of high soil moisture content described earlier. In all trials conducted so far good trash burial has been achieved. The mixing capability of the machine has also been measured. The technique used was to place a group of objects at a precise location in the path of the plough, coloured chalk placed at different depths were used as were numbered washers. The fate of these markers from a typical experiment is illustrated on the poster. Again good performance was achieved. In all experiments conducted to date the degree of soil shatter has been greater than that of the mouldboard plough. The performance of this machine will be further evaluated both in terms of measuring the power requirement and soil physical effect over a range of conditions in order that its capabilities can be firmly established.

Figure 3. Field trials at Nafferton Farm, University of Newcastle upon Tyne. 1994

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MACHINERY SYSTEMS FOR THE INCORPORATION OF CHOPPED AND STRIPPED STRAW ON A CLAY SOIL

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ABSTRACT

Following the development of the "stripper header" for combines, which strips grain directly from the plant stem, a five year field trial was undertaken to determine the most appropriate means of incorporating the long straw residue and to ascertain its effect on subsequent crop performance. Conventional mouldboard ploughing was compared with disc cultivating to bury or mix in both the stripped straw and chopped straw from a conventional harvester. Results showed that extended clearance ploughs and improved designs of skim coulter were needed to prevent blockages with stripped straw, and complete inversion could only be achieved reliably by introducing flexible deflectors. Disc cultivators could deal with stripped straw effectively, but the cost of doing so on heavy soils may equal that of ploughing. Stripped straw decomposed marginally slower than chopped straw and may reduce slightly the yield of wheat on heavy soil.

INTRODUCTION

The "stripper header" which was developed by Silsoe Research Institute as an alternative means of crop gathering, can significantly increase the rate of harvesting.[1] This rotary comb-type mechanism was designed to strip the seeds directly from the crop, leaving most of the straw and stems of the crop standing with their roots firmly attached to the soil. As the new stripper design came closer to being a commercial reality with widespread uptake, it was considered necessary to investigate the means by which the standing crop residue could be incorporated satisfactorily into the soil.

The objectives of the work were:

(1) to determine whether conventional techniques of cultivation could be used to incorporate stripped barley and wheat straw;
(2) to identify any agronomic problems associated with stripped compared with chopped straw;
(3) to determine the relative rates of stripped and chopped straw decomposition;
(4) to develop enhancements for a conventional plough so that complete burial of stripped straw could be achieved.

MATERIALS AND METHODS

Field trials were carried out on a site, which had a slight downslope from West to East, on a clay soil of the Evesham series[2] (Table 1). Winter barley was grown in the two seasons prior to the trial and winter wbeat was single cropped in each year of the experiment, which ran for five years from 1987. The plots, which measured 24 m by 36 m, had 18 m buffer and sampling zones between them and were laid out in a randomised plot design having three blocks separated by 18 m wide headlands.

Table 1 Description of the experimental site and treatments

Soil taxonomy:	clayey, mixed, mesic aquic eutrochrept[3]
Mineral constituents, % by weight[3]:	
	Clay 54.3; Silt 20.6; Fine sand 25.0; Coarse sand 20.0
Mean annual rainfall, evenly distributed, mm:	566
Elevation above mean sea level, m:	65
Latitude, degrees North:	58
Soil water content at primary cultivation, % dry basis:	
	1987 34-37; 1988 30-37; 1989 11-24; 1990 16-24; 1991 22-30
Treatments	
1.	Plough on chopped straw
2.	Plough on stripped straw
3.	Mixaplough or Disc harrow on chopped straw
4.	Mixaplough or Disc harrow on stripped straw

Two primary tillage treatments were applied on the stripped and chopped straw plots and these reflected the current U.K. practice of inversion or mixing in of the residue. The mouldboard plough was conventional in all but its under-beam and point to point clearances which were extended to 685 and 990 mm respectively. The Mixaplough was a prototype machine used in the first two years of the trial. This machine was chosen because it has good potential for burying large quantities of surface residue without blocking. However, because it became apparent that its commercial uptake was going to be limited, this treatment was later substituted by a conventional heavy duty disc harrow. Secondary tillage implements were selected according to the prevailing soil conditions.

The plots were harvested using a combine fitted with a conventional cutterbar and integral straw chopper or stripper header as appropriate. In the first two years of the trial, two separate harvesters were used but thereafter one machine was fitted alternately with the two different headers. Yield measurements were obtained from four cuts taken over the full length of each plot using a 3.6 m wide stripper header and a 3.8 m wide conventional cutterbar.

Where possible, all tillage operations and their timing were in line with normal commercial practice. Thus primary cultivations commenced in early September and drilling of the crop was planned for early October. On all occasions the crop was drilled with a three-point linkage mounted 4 m wide disc drill having an inter-row spacing of 125 mm.

During cultivation, measurements were made of tractor fuel use, wheelslip and forward speed and implement depth of work. In some years measurements were also made of implement draught with a three point linkage dynamometer[4] and tractor power take-off (p.t.o.) power using a commercial torque and speed transducer. Crop establishment was measured by counting plants within 0.25 m^2 quadrats at ten random positions on each plot.

To determine whether there were any differences in straw decomposition rates between treatments, samples of straw were extracted from six positions on each plot during the growing season. These fragments of straw were dried and cleaned before being analysed using the method described by Harper and Lynch[5] in which the proportion of lignin remaining in the sample was compared with an original figure for the straw. The weight loss of straw could then be determined from the apparent increase in the proportion of lignin present.

Development of enhancements to a conventional plough were undertaken in cooperation with a manufacturer in a range of soil types to improve the burial of stripped straw.

RESULTS AND DISCUSSION

Primary cultivation

The draught requirement of the Mixaplough was very similar to that of the plough, but, largely due to less weight transfer, tractor wheel slip was greater. This led to a reduction in efficiency and a greater fuel consumption and energy requirement. In 1990, the well structured soil resulting from the dry autumn conditions of 1989, which had persisted over-winter, led to lower energy requirements for ploughing and these were comparable with those required to disc in the chopped residue (2 passes). The need for a third pass of the disc harrow on the stripped straw meant that this system required more energy than the mouldboard plough treatment. Table 2 provides a summary of the primary tillage operations in typical years of the experiment together with performance data. There were no discernable differences in draught or energy requirement between ploughing in stripped compared with chopped straw, but there were considerable differences in energy use between years, as would be expected.

Performance of the mouldboard plough in terms of straw burial was satisfactory when operating in chopped straw, but on the stripped straw plots some of the material was often left protruding between the furrows. In 1987 the Mixaplough provided a degree of burial similar to the plough, but in 1988 a superior result was obtained compared with the plough. The Mixaplough also resulted in a greater fragmentation of the soil, but in moist conditions on this heavy soil, it could leave an uneven finish. In 1989 soil water content was low (Table 1) with a resulting increase in soil strength. Trashboards were used on the mouldboard plough instead of skim coulters, which had insufficient leg strength. This compromised the burial of the straw. An improved design of leg can now be fitter on ploughs with higher underbeam clearance. In 1990, the stripped straw was rolled in the direction of ploughing, which improved the burial of the straw, but a few plough blockages occurred. In 1991 the conditions were close to being ideal for cultivation and the minimum number of operations were required on all plots.

In 1989 a disc barrow weighing 84 kg/disc was unable to provide sufficient depth of operation. A 164 kg/disc machine was therefore introduced in 1990, and rolling at 90° to the direction of discing aided the incorporation of stripped straw. In 1991 soil conditions were ideal for cultivation and only one and two passes of the discs were needed in the different straw conditions respectively. In all cases rolling was carried out between passes. This had the effect of crushing aggregates, conserving moisture, and in the case of disc barrowing, ensuring a firm surface into which the discs would operate without blocking.

Table 2 Primary tillage operations, work rate and energy use.

Implement[1]/ year	Forward speed, km/h	Depth of work, mm	Implement draught, kN	Labour requirement, h/ha	Fuel energy, MJ/ha
Plough 1.78 m					
1987	4.8	163	45.1	1.17	407
1990	6.3	210	n.r.	0.89	272
1991	6.4	200	38.5	0.88	238
Mixaplough 1.68 m					
1987	4.5	159	46.2	1.32	501
Disc harrow					
1990 2.83 m 1st pass	6.3	100	n.r.	0.56	155
2nd pass	5.3	110	n.r.	0.67	127
3rd pass[2]	5.2	120	n.r.	0.68	116
1991 3.05 m 1st pass	6.2	150	44.3	0.53	163
2nd pass	5.5	125	n.r.	0.60	94

1. Description of implements (m, implement width)

Plough. 5 furrow fully mounted with 685 mm underbeam and 990 mm point to point clearance and 355 mm furrow width.

Mixaplough 3 module fully mounted implement with each module having a leading 500 mm diameter flat vertical disc followed by a small mouldboard and large (760 mm diameter) concave disc angled at thirty degrees to the direction of travel. Slatted deflectors continue the soil flow and inversion.

Disc harrow Offset machine with two disc gangs having 710 mm diameter discs spaced at 305 mm and with a mass of 164 kg/disc.

2. On stripped straw treatments only

Secondary cultivation

The need for and performance of secondary cultivation implements was largely dictated by the preceding weather and soil conditions rather than differences in primary cultivator performance on the stripped and chopped straw plots. Therefore, where rather poorer degrees of straw burial had been achieved by the primary cultivation, these generally remained apparent following secondary cultivation.

System performance

Table 3 provides a summary of the performance of the primary cultivation and seedbed preparation systems for three years. Overall the data show that there is no advantage to be gained from using discing as a primary cultivation compared with ploughing for stripped straw. Similarly, only in favourable seasons is discing in of chopped straw of any advantage on this soil compared with ploughing. Experience has shown that discing can be advantageous in very dry clay soils.

Straw decomposition

Two analyses were carried out on the rate of decay of the wheat straw, namely an analysis of variance for each year and an analysis which combined the information over years, treating years as a super-block. In general about 60% of the straw weight was lost during the season, although in 1990/91 this rose to about 70%. Only in 1989/90 did straw condition (chopped versus stripped) have a significant effect on the rate of decomposition, resulting in a slightly lower rate of decay (circa 10%) of the stripped straw. In 1990/91 the plough treatment resulted in an apparent increase in the rate of decay of the straw compared with the discing treatment, but neither of these isolated differences were apparent in other years, nor were they apparent in the year on year analysis.

Table 3 Summary of cultivation system labour and energy requirements.

	Treatment (see Table 1 for key)			
Year/measure	1	2	3	4
1987				
Labour, h/ha	2.50	2.50	2.66	2.66
Fuel energy, MJ/ha	693	693	754	754
1990				
Labour, h/ha	2.11	2.11	2.86	3.54
Fuel energy, MJ/ha	489	489	555	671
1991				
Labour, h/ha	2.09	2.09	1.53	2.12
Fuel energy, MJ/ha	407	407	321	415

Crop yield
Table 4 provides a summary of the yield results which were combined over years to provide an estimate of the variance components by the method of Residual Maximum Likelihood. These indicate that the type of tillage had no significant effect, but there was evidence to suggest that the stripped straw led to a slight reduction in yield on this soil type. Some of this difference could be ascribed to slightly greater losses at the stripper header. Further research would be needed to determine the exact nature and cause of this slight reduction and an economics study undertaken to evaluate the effect on farm profit, taking account of the improved harvest work rate compared with loss in yield potential.

Table 4 Crop yields, t/ha at 85% dry matter, meaned over the five years of the experiment and analysed using information combined over years.

	Tillage treatment		
Straw condition	Plough	Mixaplough/Disc	Mean
Chopped	6.72	6.96	6.84
Stripped	6.51	6.69	6.60
Mean	6.61	6.82	

Standard error of difference of means for same level of factor:
Straw 0.198
Cultivation 0.172

Improvements to the plough for complete burial of stripped straw
The performance of the plough needed to be improved to prevent blockages when operating in moist, loose clay soils and ensure complete burial of the stripped straw. Blockages were eliminated by extending the interbody and underbeam clearances to 1.12 m and 0.76 m respectively. Also a "wrap round" skim coulter top with rounded leading edge and overhanging curved top prevented straw ridging up onto its supporting

leg, provided a good flow of soil is maintained across its face.

Complete burial was achieved using innovative flexible sheet deflectors mounted at the side of the main beam, one deflector being used for left and right hand bodies. Their flexibility allows variations in soil/residue flow over the skim to be accommodated. The overall shape of the deflectors ensures that the long straw is pushed over ahead of the soil engaging components of the plough. They hold the residue against the skim and mouldboard soil flow, and most importantly, direct it into the furrow bottom to be completely covered by soil.

CONCLUSIONS

Both mouldboard ploughs and disc harrows can be used for dealing with long straw left standing in the field by 'stripper' harvesters. On heavy soils, disc harrows with approximately 160 kg/disc are needed for adequate penetration in dry conditions, and due to the extra passes needed to deal with the long straw, may be just as expensive to operate as a plough system except when seedbed preparation is difficult. Conventional ploughs can be used to deal with the stripped straw, but inter-body and under-beam clearances need to be about 1.1 m and 0.75 m respectively to prevent blocking. Complete burial and trouble free operation can only be achieved if the plough is fitted with special skim coulters and flexible deflectors. There is very little difference in the rate at which stripped and chopped straw decomposes, but there is some evidence to suggest that cereal crop yield is slightly reduced in the presence of stripped straw on this Evesham series [2] clay. The reason for this reduction is not known. Rolling the soil after ploughing and in between passes of the disc harrow, improved tillage efficiency.

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TILLAGE, COULTER DESIGN AND EMERGENCE OF BARLEY

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ABSTRACT

Coulter design has been tested comprehensively in conventional tillage for many years. When new tillage methods like direct drilling or non-ploughing tillage are adopted, coulter design is likely to cause differences in emergence and yield.

In 1992 and 1993, field experiments were conducted to find out more about the differences. The crop grown was spring barley. Emergence was measured at intervals of 100 mm in the seed row with a measuring stick. Seeding depth was found by pulling up the seedlings and measuring the chlorophyll free length.

In 1992, four conventional coulters and three direct-drill coulters were compared. The seven coulters were tested on stubble and under three different tillage conditions with different tillage intensities. Tillage methods were deep harrowing, shallow harrowing and ploughing plus seedbed harrowing. The results show that all the factors coulter, tillage and interaction between tillage and coulter had significant effect on emergence. Conventional coulters on untilled soil gave very poor emergence. Direct-drill coulters generated emergence equal to or lower than conventional tillage coulters on the tilled parts of the plot. On untilled soil, they were capable of producing emergence at the same level as on tilled soil.

In 1993 one conventional coulter and two direct-drill coulters were compared. The conventional coulter was used in two ways, with normal load and with an extra load. All coulters were tried on tilled, loosened soil and direct on the stubble. Results showed zero emergence for the unloaded, conventional coulter on untilled soil. The extra loaded, conventional coulter gave emergence on the same level as the direct-drill coulters. There were significant better emergence for all coulters on tilled soil than on untilled soil, but the difference was higher for the extra loaded conventional coulter than for the other coulters. Both years the conventional coulters did not manage to penetrate the surface on untilled soil.

INTRODUCTION

Many Norwegian farmers are considering and adopting reduced tillage practices on their farms instead of plough-based tillage. The reasons for this change in practice can be a demand for less erosion from agricultural land, or less time consumption in production in order to cut overall costs (1, 2).

Reduced tillage means less soil inversion and as a result, more straw on the surface and in the upper soil layer. Drills designed for use in a plough-based system, may encounter problems in a reduced tillage system. One reason can be blockage of straw because the distance between soil engaging tools in the drill is too short. Straw can also pile up in front of each coulter because of the design of the coulters. This can result in uneven sowing depth and problems with emergence. These types of problems are related to the amount of straw, distribution of straw on the ground and length distribution of straw material (3).

As a part of a dr. scient. research work at the Agricultural University of Norway, investigations were carried out in 1992 and 1993 in order to find out more about coulter design and emergence of cereals. Results shown in this paper are: emergence counts and sowing depth measurements three weeks after sowing.

MATERIAL AND METHODS

Location

The experiments were done in the south-east part of Norway (NGO Map No. 1914 III Ski). The experiment in 1992 was located at Bjørnebekk, UTM coordinates 32VPM035148. The elevation is approximately 115 m above sea level. The parent material is postglacial clay, poorly natural drained. The soil contains 14% sand, 59% silt and 27% clay. In 1993, the experiment was located at Syverud, UTM coordinates 32VNM986183. The elevation is approximately 40 m above sea level. The parent material is postglacial clay, poorly naturally drained. The soil contains 34% sand, 41% silt and 25% clay.

Meteorological data

Bjørnebekk, 1992

Tillage preparation and sowing of spring barley was done 11. May. The period after tillage and sowing was dry and warm. Precipitation was 29.9 mm the first 30 days after sowing. Mean temperature in May 1992 was 12.8 degrees centigrade and in June 1992 17.3 degrees centigrade

Syverud, 1993

Tillage preparation was done 23. June. Sowing of spring barley was done at 24. June. The first 2 weeks after sowing was dry. Precipitation in June was 86.2 mm, which is slightly more than average. Mean temperature in June 1993 was 13.4 degrees centigrade and in July 1993 14.6 degrees centigrade.

Field preparation

The experimental field at Bjørnebekk in 1992 measured 50 m by 200 m. To combat weeds, the field was sprayed with Glyphosate in the autumn 1991. In spring 1992, the field was divided into 4 replications. Each replication was divided into 4 plots with different soil treatments. The soil conditions were: a) untilled, b) deep harrowed, c) shallow harrowed and d) ploughed and harrowed. Table 1 shows tillage implements used and tillage depth for each implement.

Table 1. Soil conditions, tillage implements and tillage depths

Soil condition	Tillage implement	Tillage depth (mm)
a) Untilled	None	
b) Deep harrowed	Wiberg Grubber	150
c) Shallow harrowed	Rabe Rotary harrow	50
d) Ploughed and harrowed	i) Experimental plough ii) S-tine harrow	i) 120 ii) 50

The experimental field at Syverud in 1993 measured 36 m by 6 m. In spring 1993, the filed was divided into four equal parts. Three of the parts were used as replications in the trial, and the fourth for soil sampling. Each replication had two different soil conditions: tilled and untilled. The untilled half of the plot was covered with oats-straw residue from the crop harvested in 1992. The tillage on the other half of the plot was done using a soil driven rotary harrow twice (DynaDrive). Tillage depth was 80 mm.

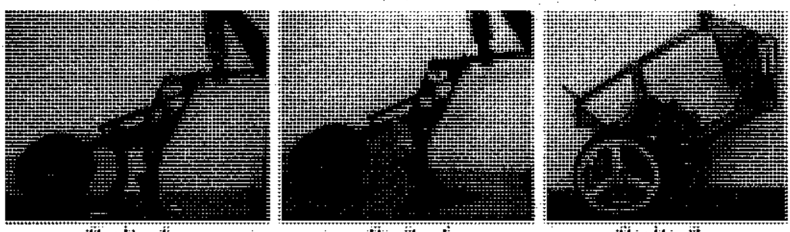
Coulters used in the experiments

Drill coulters used in 1992 were divided into two groups. The first group consisted of four different coulters designed for conventional tillage. In the second group, three direct-drill coulters were chosen. The coulters for conventional tillage were manufactured by Tume in Finland. Coulters from 1 to 4 are: single disk coulter, curved shoe coulter, hoe coulter and winged coulter. Figure 1 shows the coulters for conventional tillage used in the experiment.

Coulter 1 Single disk coulter | Coulter 2 Curved shoe coulter | Coulter 3 Hoe coulter | Coulter 4 Winged coulter.

Fig. 1. Coulters for conventional tillage used in the experiment.

The second group of coulters were openers designed for drilling various crop seeds into untilled soil. John Deere 610 is a series of openers that can be delivered in many versions. The two versions chosen both deliver fertilizer and seed. The split-row seeder with heavy-duty knife has a fertilizer boot preparing the seedrow. Seed is sown in a separate sweep blade behind the boot placing the seed in two rows, 100 mm apart. Fertilizer is placed between the seed rows, 30 mm beneath the seed. The split-row seeder with sweep has a goosefoot share which loosens the soil and prepares the seedbed. Fertilizer and seed are placed in separate rows beneath the share. Agrisystems Cross-slot has a single disk cutting the soil. Fixed winged knives at each side of the disk prepare separate rows for fertilizer and seed. All three direct-drill coulters have integrated rubber wheels packing over the seedrows. Figure 2 shows the coulters for direct drilling used in the experiment.



Coulter 5 John Deere 610 Split row seeder with heavy-duty knife | Coulter 6 John Deere 610 Split row seeder with sweep | Coulter 7 Agrisystems Cross-slot

Fig. 2. Coulters for direct drilling used in the experiment.

All combinations of tillage and coulters were tested in the experiment in 1992. This means that direct drill coulters were used on tilled soil, and conventional tillage coulters were used on untilled soil. In the latter case, emergence was expected to be low. In 1993, a smaller number of coulters were used. The aim was to find out more about emergence by using a conventional, extra loaded coulter. For this purpose, the hoe coulter, shown as coulter 3 in figure 1, was used in two configurations. First in its standard configuration mounted on a spring loaded, rear facing arm (coulter 3). Second it was mounted on the same bracket, but this time with an extra 450 N load added vertically to the soil-engaging point of the coulter (coulter 3a). For comparison, the coulters 5 and 7 where chosen. Sowing depth was adjusted to 50 mm for coulters 5, 6 and 7.

Experimental drill

To make mounting of the coulters possible, an experimental drill was made in the department workshop. The drill is equipped with separate seed- and fertilizer boxes, each with 8 outlets. Different coulters and direct-drill openers can be mounted to a toolbar. In the experiments, a different number of coulters were used depending on type. The conventional coulters (coulters 1, 2, 3, and 4) were mounted three on the toolbar, except the extra loaded hoe coulter used in 1993 which was used single (coulter 3a). The John Deere 610 (coulters 5 and 6) was mounted as a pair. The Agrisystems Cross Slot (coulter 7) was tested alone because of the high cost of the unit.

Post emergence measurements

Three weeks after sowing an emergence count was done. Because the coulters only produced 1, 3 or 4 rows of emerging plants per 3 m wide tillage row, ordinary emergence counts were out of question. A one-metre counting stick divided into 100 mm. intervals was made. The stick was placed near the seed row, and emerging plants were counted in each interval. Because the few number of rows implies a lot of space around the plants, no attempt was done to calculate the number of plants per square meter. Sowing depth was found measuring the chlorophyll free length of the seedlings. The length was measured in 5 mm intervals.

RESULTS AND DISCUSSION

Bjørnebekk, 1992

Emergence counts

The results show that emergence for conventional coulters on untilled soil was zero (Table 2). This result was expected. The table indicates better emergence for the two soil conditions shallow harrowed and ploughed, than for deep harrowed. This trend was evident for all conventional tillage coulters, but not for the direct-drill coulters. Emergence for direct-drill coulters varied less than for conventional tillage coulters on different soil treatments.

Table 2. Emergence (plants/100 mm row) for the different coulters and soil conditions used in the experiment

	Coulter						
Soil condition	1	2	3	4	5	6	7
Untilled	0	0	0	0	29.6	19.5	25.5
Deep harrowed	17.5	25.1	21.4	18.1	20.8	25.6	27.8
Shallow harrowed	30.9	33.6	36.5	29.1	29.1	29.9	33.3
Ploughed	30.6	34.8	28.8	34.5	24.0	23.5	30.3

An analysis of variance was done in order to find out more about differences in emergence. The test indicates that both main factors, tillage and coulter, and the interaction between tillage and coulter all have significant effect in the model. Separate post hoc tests were then done for coulters and tillage methods. The post test for tillage methods shows significant higher emergence for all tillage methods than for untilled. Shallow harrowing, and ploughing and harrowing gave significant higher emergence than deep harrowing. The post test for coulters shows higher emergence for coulter 5 than for coulter 1, and higher emergence for coulter 7 than for coulters 1, 2, 3 and 4. All tests were done at 5% level of significance.

Sowing depth

Table 3 shows sowing depth results. The conventional coulters did not manage to place the seed into the soil on the untilled part of the field. The coulters 5, 6 and 7 placed the seeds into the soil independent of soil condition. There were no significant difference between coulters 1, 2, 3 and 4, and between coulters 5 and 6 ($p>0.05$). Tilled soil gave better sowing depth than untilled for all seven coulters.

Table 3. Sowing depth (mm) for the different coulters and soil conditions used in the experiment

	Coulter						
Soil condition	1	2	3	4	5	6	7
Untilled	0	0	0	0	49.1	45.3	36.4
Deep harrowed	36.2	32.8	33.7	32.0	59.7	57.4	49.9
Shallow harrowed	34.0	37.8	32.4	28.5	59.4	48.4	38.8
Ploughed	37.8	44.8	38.8	33.1	59.7	57.1	47.3

Syverud, 1993

Emergence counts

The emergence counts showed clearly that coulter design meant a lot for plant growth (Table 4). On untilled soil, the results shows that the unloaded, hoe coulter give no emergence at all. Coulter 7 gave the best emergence, and coulters 3a and 5 gave emergence at the same level. On tilled soil all coulters gave better emergence than on untilled soil. Coulters 3a and 7 gave better emergence than the other coulters. Increase in emergence from untilled to tilled soil was highest for the two hoe coulters.

Table 4. Emergence (plants/100 mm row) for the different coulters and soil conditions used in the experiment

	Coulter			
Soil condition	3	3a	5	7
Untilled	0	15.5	15.5	20.5
Tilled	19.7	27.0	20.0	24.8

Sowing depth

Results show that the conventional hoe coulter do not manage to place the seeds down to an adequate depth in untilled soil. On tilled soil, all four coulters manage to sow to the depth as adjusted on the drill (Table 5). The two direct-drill coulters are not dependent on soil condition to achieve the correct sowing depth.

Table 5. Sowing depth (mm) for the different coulters and soil conditions used in the experiment

	Coulter			
Soil condition	3	3a	5	7
Untilled	13.2	31.0	45.7	35.5
Tilled	38.7	43.3	39.0	41.7

CONCLUSION

This paper is written on the basis of one of several coulter-tillage experiments carried out at the Agricultural University of Norway. The results presented in this paper are from two field experiments sown in May 1992 and June 1993. Emergence counts and sowing depth registrations were done 3 weeks after sowing.

In 1992, the weather was warm and dry the first month after tillage and sowing. Factors tillage and coulter, and interaction between tillage and coulter all gave significant effects on emergence in the statistical analysis. On untilled soil, only direct-drill coulters managed to place the seeds into proper sowing depth. The highest emergence for all coulters, was found in the plot tilled with the rotary harrow at 50 mm working depth. The second best emergence was found in the ploughed and harrowed plot, but the difference is not significant. Deep harrowing gave lower emergence than the other two tillage treatments. This was evident for all conventional tillage coulters. On the untilled stubble, only the direct-drill coulters managed to produce emergence. These coulters were capable of producing emergence under all soil conditions tested.

In 1993, the weather was dry the first two weeks after sowing. A extra loaded, conventional coulter managed to place the seeds into untilled soil, and produced emergence at the same level as the two tested direct-drill coulters. On tilled soil, the loaded hoe coulter and the Agrisystems Cross-Slot coulter gave the best emergence.

Both tillage and sowing mean a lot for emergence of barley. On untilled soil, the coulters must manage to put the seeds into proper depth. On tilled soil, the coulter must work to an even working depth. The direct-drill coulters used in the experiments managed to sow under various conditions. Conventional coulters requires a tilled condition, but an extra loaded conventional hoe coulter managed to sow on untilled soil.

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THEORETICAL BASES FOR DETERMINATION OF THE MACHINE DEGRADATION OF SOIL

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ABSTRACT

By means of the information theory the level of the machine degradation of soil has determined and the decrease of the crop yield forecast. This methodological conception is based on the express-diagnostical experiments in field and laboratory conditions. To this end we are using the special Algorithm of complex estimation of the machine degradation of soil.

INTRODUCTION

Machine degradation of soil (MDS) is one of the component parts of general soil degradation due to the effect of anthropogenic factor. With this factor absent, the soil is in its natural state and controlled by natural processes taking place in nature. By the agro-ecologic estimation of machine degradation of soil, such natural state of a fallow (grass-land) was taken as basis for evaluation.
In Estonia where up to the recent times intense agricultural use of land was practiced and where now the lands are being returned to actual owners, it is of great importance in what state of machine degradation they are taken into economic use again. Every owner is striving to a sparing use of land. However, not everybody has a clear idea of how this should be done. Therefore it is expedient to work out methodology for estimation of machine degradation of soil which for Estonia in the process of development as well as for other Baltic States, should be possibly cheaper and most efficient.

MATERIALS AND METHODS

For determing the allowed on soils machine degradation and obtaining an adequate picture of the final results of mechanical influence of mobile technical means on soil, the express method has been worked out. This method is based on the principle of separation of gutta liquid at a constant temperature (23°C) and at up to 100 per cent of air humidity. This is achieved in a hydrothermostat. Additional evaporators, in other worels, water tanks, are placed into an ordinary thermostat, for germination of seeds. Germinated seeds are sown into cylinders of 8 cm in height and 6 cm in diameter.

In 48 hours for barley, 3 cm germs of whitish colour will spring up. On these germs dewdrops appear. The humidity or density of these drops is varying depending on soil conditions.

At higher densities the gutta liquid is totally absent. The germs of the seeds are unable of developing. The gutta liquid can easily be collected on filter paper where a blot appears. The area of the blot can be determined by weighing or by a planimeter. We used the latter. For better determining the contours of the blot, the filter paper should be treated with 5 per cent copper vitriol solution. The above is the description of the principle the gutta diagnostical method. For specifying the limit of normal strain in soil at a depth of 10 cm in laboratory conditions, the odometer was used.

Proceeding from the practical point of evalution of machine degradation of soil, compactive data on the estimation of relative guttation and relative crop yield were taken as the basis. If as a result of machines' work in the field, neither relative guttation nor relative yield decreased by not more than 1 per cent, calculated from the best (maximum) result (100 per cent), then, at 0.8FC of soil humidity, its condition was not impaired remarkbly. For to specify the extent of deterioration and its allowed level, the respective theoretical bases were worked out.

The estimation of machine degradation of soil is based on information theory. First, the problem of optimization had to be solved. Algorithms of the estimation of machine degradation of soil are given in the Figure where:

P_a is air-filled porosity of soil (allowed 15 per cent); "d" is density of solid phase (calculated value 2.61 g/cm^3); W_{mg} - humidity of maximum guttation, the analog of the minimum water holding capacity, specified experimentally; Y_1, Y_f, Y_o is bulk density of soil, determined in laboratory and field conditions, respectively, and its allowed value, specified by the method of guttation (by E.Reppo); a_p, b_p are empirical coefficients of transition from Y_1 to Y_f (varying from light to heavy soils within the limits of a_p = 0.96...2.44, b_p = 0.05...1.04, for medium sandy loam the recommended calculated value is a_p = 1,65, b_p = 0.65; h_a is depth of active layer which is most adversely affected by machine degradation; ß is coefficient of distribution of compressive strains on the depth of soil massif; 6_i, 6_{xo}, respectively, are compressive strains at the depth of 5 cm (conventionally contact running gear with soil) and at the depth of active layer where it is still possible to record residual deformation of soil; A_1 and A_3 are degrees of soil compactness specified under the conditions of its possible lateral extension and without this possibility; a_x, b_x are experimental coefficients, determined at compression of soil (varying from light to heavy soils in the limits of a_x = (1.66...1.00)10^{-2}, b_x = (3.86...3.50)10^{-3}, for medium sandy loam the recommended calculated value is a_x = 1.08 10^{-2}, b_x = 3.05 10^{-3}; μ_A - coefficient of transmission of A_3 to A_1 which at a soil humidity corresponding to the humidity level of the minimum water holding capacity, is approximated by an equation $\mu_A = 0.6\ 0.988^{Fs}$, where Fs is the content in per cent of particles, with <10µm in diameter in soil ("physical clay" by Kachinski).

Further, a_a, $ß_a$, $\&_a$ are empirical coefficients of dependence of relative crop yield degree of compactness of soil. The degree of compactness of soil A, in its turn, is calculated by means of the formula

$$A = \frac{(Y_1 - Y_{min})\,Y_k}{(Y_k - Y_{min})\,Y_i},$$

where Y_{min} is the density of soil in its loosened initial state (heaped); Y_i is current value of soil bulk density; Y_k is limit bulk density of soil in the state of compaction, at which plants are no more able of growing. Proceeding from conditions and possibilities of aeration of soil, relative crop yield can be expressed through the bulk density of soil directly by means of the equation
$K_a = a_a Y^2 + ß_a Y - \&_a$. The physical sense of the given empirical coefficients is analogous to those above in algorithm (ref.7). Here the given empirical coefficients vary within the limits: $a_a = (3.92...8.00)$, $ß_a = (8.34...19.82)$,
$\&_a = (3.10...13.47)$. Whereby, for example, for turf-gley saturated medium sandy loams the respective empirical expression will be: $K_a = 6.13Y^2 + 13.23Y - 6.14$, whereby, if n=9, the minimum value of correlation relation equals 0.74+/-0.25, Students criterion being $t_f=2.91 > t_{05}=2.37$.
The residual indeterminancy of ref.10 of the given algorithm is calculated departing from the difference between the entropy of maximally deteriorated agro-ecological state $H(Q)_{SD}=1$ and current value of entropy $H(Q)_i$. Analogically information capacity I_n of the system "Machine-Soil-Plant" is determined, starting from the most favourable situation when $H(Q)_{SI}=0.1$, taking into account natural background. At the i-th and z_e standard influence information values are determined. As a result, a relative measure (from the point of view agro-ecological estimation) of the level of adverse influence can be determined to which (from the point of view of three-gradational estimation) in its turn, three effects of different characters can be adhered to: soil deteriorating (SD), soil sparing (SS) and soil improving (SI). If the necessity arises to relate conventional effects with physical levels, as at soil compaction by wheel or track passes n_f, this can be described by means of the aquation (ref.14) of algorithm.

RESULTS AND DISCUSSION

It has been proved by investigations that when using a tractor soil tillage outfit (wheel tractor t-150K of 3T tractive power with a trailer implement PYM-8 for sowing mineral fertilizers) where the load on tractor wheels is $P_T=25$ kN, and that on trailer wheels is $P_n=21$ kN, the dependence between the physical number of wheel passes is described by an empirical equation
$n_f = 0.92(N_y - 1)$. Our investigations have shown that in the middle part of the wheel track the decrease of the crop yield may reach 42 per cent, that is $k_a=0.58$ (see algorithm ref.8). In this case as a result of calculation of the algorithm $N_y=504$ and $N_f=460$.

Taking into account the allowable limit of agro-ecological bearing capability of soil at which the crop yield practically should not go down (a decrease by 1 per cent is allowed), i.e. k_a=0.99, the following estimation parameters, giving a complex characterization of the allowable level of the condition of soil, are proposed: $A_{SS}=3.3\ 10^{-3}$; $H(Q)_{SS}=3.2\ 10^{-2}$; $I(Q)_{SS}=0.968$; $z_{SS}=1.07$.
Putting into practice of the algorithm given above, has been effected on the example of tests with air-tired half-crauler, belt reinforced half-crauler running gears to tractors MTZ-82 (worked out by Belarus Polytechnical Institute) in comparison with wider wheels taken over from tractor K-700 (model FD-12, 2.84-26.2") and ordinary wheels of an analogous tractor MTZ-82. As is shown by tests in extremely hard conditions at the Matsalu Nature Reserve, the best results were obtained by using a 1.4 T tractor (class of tractive power) belt half-crawler running gear. Maximum pressure on soil did not exceed 50 kPa. This kind of running gear corresponds to the conditions of agro-ecological bearing capability if the humidity of soil (turfed background) does not exceed 1.0 of FC. According to our investigations the said belt half-crauler tractor caused a decrease of crop yield by 5 per cent hence k_a=0.95, N_y=1.35 and n_f=0.3. To a certain extent poorer results were obtained (with over 10 kPa) when using extended running gear (wheels of model FD-12). With the use of latter, the allowable limit of soil humidity is 0.9 of FC. In this case the result of mechanical effect specified by means of the given algorithm, will remain within the above limits. It was proved by the analogous investigations that crop yield decreased by 6 per cent, hence k_a=0.94, N_y=1.46 and n_f=0.4.
When using air-tired half-crauler running gear of tractor MTZ-82, the maximum pressure exerted on soil is up to 70 kPa, resulting in a probable reduction of crop yield by 11 per cent. Thus k_a=0.89, N_y=2.13 and n_f=1.04 1.0. In order words, as compared to the worst case (T-150K + PYM-8), the use of this type of running gear is so soil-sparing that the above described negative influence on soil can be achieved only by passing the same tracks some 50 times. In order to avoid such an adverse effect, this kind of running gear can be used if the humidity of soil does not exceed 0.8 of FC. As far as ordinary wheels (model F-2A, 15.5-38"), used by tractor MTZ-82) are concerned, the maximum compressive stress on soil of the order 110 kPa was obtained, which even exceeded the stepping on the sensor by an Estonian heavy-weight farmer, weighing 110 kg and wearing boots of size 45. Dancing on the sensor, he achieved the maximum pressure of 85 kPa.
Working with tractor MTZ-82 with ordinary wheels (standard version) the proposed allowable values of agro-ecological estimation parameters will be provided at a soil humidity not in excess of 0.6 of FC. Ignoring this requirement, a decrease of grass yield by 20 per cent may be expected which is to be considered a great loss, and an adverse effect of soil compaction is likely to last for many years until natural biological processes, making for the restauration of the previous state, bring this biocenosis back into its state.

CONCLUSIONS

As a result, it has been proved that for Estonian soils the allowable values of agro-ecological bearing capability of soil q_S are as follows:

- 20 kPA for hydromorphic soils
- 40 kPa for semi-hydromorphic soils
- 100 kPa for automorphic soils.

The maximum values of contact strains σ_{SS}, forming in the uppermost layer of soil due to passing it by running gear (RG) of mobile technical means (MTM), should not exceed the above-mentioned values with the soil humidity being 0.8 of FC (80 per cent of the minimum watter holding capacity of soil).
With the observance of the specified conditions of soil state, it is possible to maintain a soil sparing character of mechanical influence and agro-ecological bearing capability of soil, whatever the running gear be.
For each soil with its specific ecological background it is expedient to specify the allowable limiting values of agro-ecological bearing capability which is the final criterion for use of particular running gear mobile technical means.

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1. $$Y_1 = \frac{(1-p_a)d}{1+1.1W_{mg}d}$$
$p_a = 15\%$ or 0.15

2. $$Y_f = a_p Y_1 - b_p$$

3. $$h_a = 1/\beta \; Ln(\sigma_{SS}/\sigma_X)$$

4. $$h_i = h_a(1 - Y_a/Y_f)$$

5. $$A_3 = 1 - \exp\left(\frac{a_X \sigma_{SS}}{1 - b_X \sigma_{SS}}\right)$$

6. $$A_1 = \mu_A A_3$$

7. $$k_a = a_a A^2 + \beta_a A - \delta_a$$

8. $$E_Q = \frac{1-k_a}{1-k_{SD}} = 1.25(1-k_a)$$
if $k_{SD} = 0.2$

9. $$H(Q) = E_Q Log_2 1/E_Q + (1-E_Q) Log_2(1/1-E_Q)$$

10. $$I(Q) = H(Q)_{SD} - H(Q)$$
$$H(Q) = 1 \quad H(Q)_{SI} = 0.1$$
$$I_n = H(Q)_{SD} - H(Q)_{SI}$$

11. if $k_a = 0.99$
$$E_Q = 0.0125$$
$$I_n = 0.90$$

12. $$z_i = \frac{I(Q)}{I_n}; \quad z_e = 1; \quad N_Y = \frac{z_e}{z_i};$$

13. $$n_f = a_F(N_Y - 1)$$

Figure.
Algorithms of determining general and informative characteristics of the state of system "Machine-Soil-Plant"

METHODOLOGY OF SOILS PHYSICAL PROPERTIES OPTIMIZATION

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ABSTRACT

The proposed methodology includes the definition of real and optimum parameters of soil cultivated layer structural composition and bulk density, formulation of agronomical demands to corresponding technological procedures and technical means at cultivation of agricultural crops on Ukrainian typical thick heavy-loamy chernozems.

INTRODUCTION

Published during last years materials on investigation of old arable soils physical properties, in particular chernozems [1,2], show that their bulk density and structural composition (key indices from which depend water, air and to a certain degree, nutritive regimes) are substantially deteriorating mainly under effect of unreasonable cultivation methods and technological means. Detected in this overcompaction and destroying of aggregates in the cultivated layer, even under conditions of adequate water supply and optimum nutritive regime, do not permit realization to the full extent of the adaptive and production potential of modern varieties of agricultural crops. Therefore, an important task consists not only in the ceasing of the soil agrophysical degradation process, but also in the forming in the root layer of mentioned properties approaching on their parameters to demands of cultivated crops. Starting from this, there have been determined the purpose of the present work - to substantiate the methodological approach to the parameter optimization of structural composition and bulk density of the arable soil tilled layer. Initially it was assumed to determine the optimum parameters of sought-for indices regarding grain ear grops. At the same time it was necessary to find real parameters of the same characteristics of cultivated layer under production conditions. Comparison of real and optimum parameters permitted to formulate the soil-physical part of demands on technologies and technical means, which partly have been realized in the form of combined soil tillage and sowing machines able to form the optimum soil structural composition at crops sowing, decrease the bulk density in the layer under seeds and effect the seeding.

OBJECTS AND METHODS

The investigations have been carried out on the chernozem typical thick heavy-loamy in the left bank forest-steppe on Institutes experimental farms in Kharkiv region. The soil was characterized by following parameters in the cultivated layer, important for the interpretation of physical properties: humus content 5.2%, particles less than 0.01mm - 57%, less than 0.001mm - 35%, exchangeable calcium in the colloidal comlex - about 85%.

Optimum parameters of bulk density and structural composition have been determined in special experiment planning methods. The distinction of proposed approach at finding of the optimum structural soil composition consisted in that, that yields of barley and other grain crops have been investigated depending not on seperate structural fractions, but on their ratio (mixture), which is more adequate to real conditions. The problem of investigation of the effect of soil structural composition on yield was reduced to the study of characteristics of 4-component mixtures: crumbes 20-5mm (X_1), structural separates 5-2mm (X_2) and 2-0.25mm (X_3), and silt-less than 0.25mm (X_4). The compound plan of the experiment has been developed on the basis of simplexlattice plans [3]. The yield and other optimization parameters of the arbitrary mixture were calculated at a computer and by interpolation. The results of investigation are presented on the tetrahedron scanning (simplex), where are separated zones with the optimum ratio X_1, X_2, X_3 and X_4 to which corresponds the maximum yield. Mentioned experiments have been carried out in vegetation vessels and microplots 1x1x0.3m under field conditions.

Fractional factor experiment and plans of Box and Hartley [4] have been used for finding of the optimum bulk density of cultivated layer and its separate parts. A standard method of regression analysis, except of already mentioned, where as separate factors were used fertilizers, has been used at the computer treatment of such a multifactor experiment. The sought-for parameters are printed-out as pictures of isoquants. The microfield experiments on plots 1x1 with the depth of 0.15-0.50 m was the main one in these trials. In such experiments the dynamics of given factors has been checked.

The real parameters of bulk density and structural composition have been investigated on the same soil in production sowings of barley and other grain crops during their vegetation in 1985-1992.

RESULTS AND DISCUSSION

Real and optimum parameters of structural composition.

Real parameters in separate part on the root layer of various size structural aggregates on sieving on screens in air-dry condition depended in general on the moistening level and year's season. In the dry year the structural composition of the overseed and underseed layers was substantially worse than in a moist year. At the middle of vegetation there was observed improving of structural composition , which at the crop harvest was replaced by accumulation of large aggregates at the expense of smaller. The structural composition of the underseed layer was somewhat better than of the overseed layer. Mean indices for the structure of the first observation term (during the sowing) in the investigated period are representated in the table 1.

Table 1. Real and optimum physical parameters of the arable layer of investigated chernozem of barley cultivation (mean data for 1985-1992)

Separate cultivated layer parts, cm	Soil structural composition at sowing on the aggregates ratio $(X_2 + X_3)/X_1$*		Soil bulk density at sowing, g/cm^3		Direction (±) and size of changes in physical properties at sowing	
	real	optimum	real	optimum	structural composition	bulk density
Overseed, 0-8	2.0	2.8	1.18	1.10	+ 0.8	-0.08
Underseed, 9-21	-	-	1.25	1.05	-	-0.20

* Designations in the text. As the [on 5] fraction in no experiment exceeded a critical value of 25%, when its deteriorating effect on mixture properties becomes substantial, this value was not used in the calculation of the aggregates ratio.

The optimum structural composition in the overseed layer at the barley sowing was as follows: $X_1 = 22.5\%$, $X_2 = 32\%$, $X_3 = 32\%$, $X_4 = 14.5\%$; or $(X_2 + X_3)/ X_1 = 2.8$; in this the demands of barley determined on grain are higher than on above ground mass (the zone of maximum yield at the fig. 1,b is less than at the fig. 1,a). At the same ratio, nutrition elements and moisture are used more effective. In the maximum zone 1.7 l moisture are needed for obtaining of 1g yield, in the minimum zone - 2.4l.

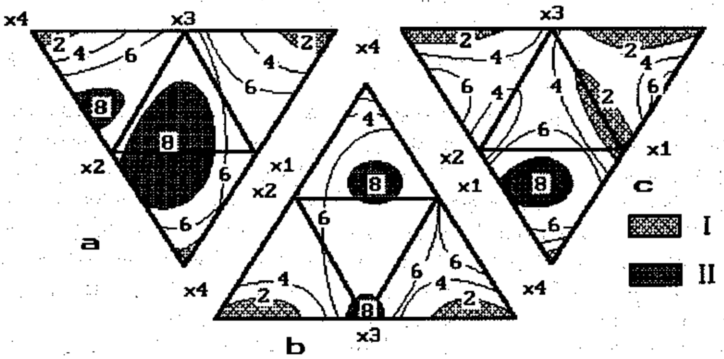

Fig. 1. Dependence isoquants for various yield of above ground barley plant parts (g/vessel,**a**), grain mass (g/vessel,b) and plant uptake of N+P+K (mg/vessel,c), on the ratio of soil aggregates X_1, X_2, X_3 and X_4.

Isoquants are drawn for **a** with interval 2.3g: 2-15.3; 4-17.6:6-19.9; 8-22.2;

for **b** with interval 10.0 mg: 2-112;4-122;6-132;8-142.

I - zone of minimum yield; II - zone of maximum yield.

Real and optimum parameters of bulk density.
Real parameters in the cultivated layer also distinguish by pronounced dynamics both during vegetation period and on investigation years. There are reflected in the table only mean results during sowing after fall plowing and presowing harrowing.Optimum parameters have been revieled in multifactor experiments,one of which is shown on the fig.2. It is obvious from it that the optimum bulk density of the overseed layer at barley cultivation is in the interval of 1.05-1.15 g/cm^3, of the underseed layer-near to minimum value of the given factor before sowing. And although the importance of the latter during vegetation somewhat increased, its "residual" effect reliable maintained to the end of crop vegetation. The same results have been obtained in all years of investigations.

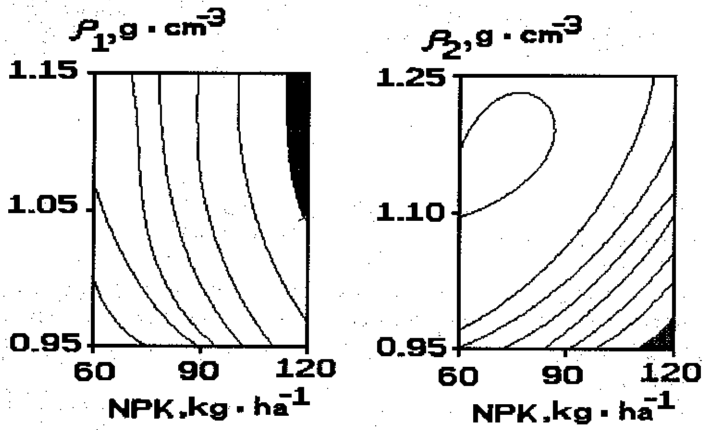

Fig.2. Isoquants of barley dry bagasse mass(g/m^2) depending on soil bulk density in overseed (ρ1) and underseed (ρ2) layers and on fertilizers rate.

The interval between isoquants 66 g/m^2, the zone of maximum yield of 1326 g/m^2, is shaded.

Thus, the many years comparison of real and optimum parameters of physical properties indicates the necessity to aim at soil discompaction in aboveseed and particularly in underseed layers and a structure formation in the abovessed layer. The latter composed the basis of agronomical demands, on the basis of which there have been created the experimental specimens of two combined soil tillage and sowing machines. One of these machines (fig.3) functions as follows: the ploughshare 1 cuts the soil to the depth of seeds coverage and with the aid of directing discs 2 feeds it to the rotor loosener 5. Seeds are placed by the shoe 3 under the ploughshare. The rotor loosener turns the lower moistened soil layers,made it finer and facilitates spilling of fine aggregates through openings in vibrating grid 4. Screened agronomically most valuable soil aggregates in dimension less than 5 mm cover the seeds. Remaining on greed coarser aggregates are concentrated in the upper layer.Rolling-on packer 6 packs the soil creating in this the best contact of seeds with fine aggregates.

Another machine is provided with tillage tool of a flat-wedge type, which is able to move at the depth from 10 to 25 cm and produces a weak soil stirring at this depth causing its discompaction.

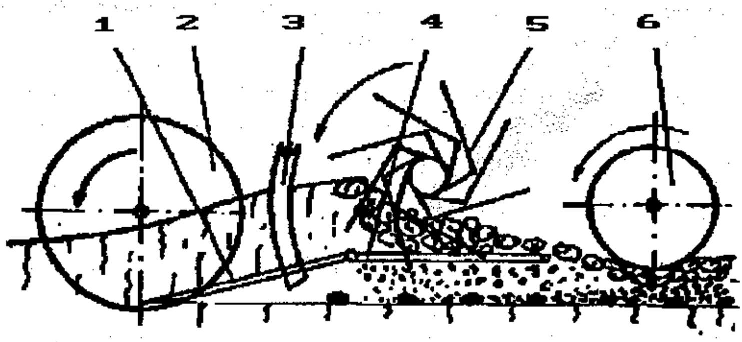

Fig.3. The technological scheme of a combined machine, for the optimization of soil structural composition. Designations in the text.

Both machines passed a three-four years cycle of energetical and agronomical tests on cultivation of grain crops and demonstrated the reliable efficiency.

The first machine (for the optimization of soil's structural composition in the aboveseed layer) gave stable and reliable grain yield in every from four observation years (1987-1990). The mean yield on the control (standard technology) was 5.22 t/ha barley grain, and in the variant where was applied developed by us machine instead of presowing cultivation, usual seeder and soil packing- 6.00 t/ha.

The second machine (for discompaction of soil bulk density in the underseed layer during sowing) was tested under field conditions during three years (1991-1993). There have been obtained following results: yield at the control - 3.66 t/ha barley grain, and in the variant with the machine - 4.85 t/ha.

CONCLUSIONS

The chernozem typical thick heavy-loamy has a coarser structural composition and raised bulk density than needed for cultivation of grain crops. It is possible to improve the structure of the aboveseed layer on the soil tillage with a special machine performing the separation of soil during its elevation and discompaction - with the machine having tillage tool of a flat-wedge type tilling soil in the underseed layer before (or during) sowing.

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A RE-NEWED EVALUATION METHOD OF PLOUGH BODY

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ABSTRACT

In the latest years, a lot of new development works was done by plough disegner to improve the effects of plough body. As a result of the improvement the working quality and draft requirement of the bodies has been changed. It is not known whether the changes due to the new disegn or the modification of the moldboard shape. To give the right answer we renewed an old evaluation technique. Using the slit-light method we tested a body of the Szabó roller plough, the Howard swing plough, the Huard Losange plough and a Rabewerk slat-moldboard. Evaluating the characteristic curves formed by the vertical intersection of the moldboard surfaces was found that the renewed technique is useful to define the type of a new body and its suitability to soil types.

INTRODUCTION

The development of the plough disegning and manufacturing gave us a large number of new and renewed plough bodies. Some of them have not a simple, conventional form of moldboard even they have a very special multi-part one, like for example the Szabó-type roller plough. To define the accurate type and suitablility of the special moldboard is not an easy task. For description of moldboard shape a large number of methods (mathematical, graphical, optical) have been developed by various researcher including White, Ashby, Krutikov, Soehne and others. They used own methods both to describe the shape and to try to establish design equations.

In our study we tried to find a method to define the type of bodies and their suitability to our climatic and soil condition only. Studying the different methods we chose the slit-light one, because this procedure is not expensive and its accuracy is acceptable for us.

MATERIALS AND METHODS

For this project we collected a colorful range of special plough bodies from the late sixties Szabó-type roller plough to the latest swing plough.

The investigated plough bodies are the next:

- Szabó-type roller plough
- Slat-mouldboard from Rabewerk
- Losange mouldboard from Huard
- Square-type from Howard

First of all we defined the specification of the bodies using the system shown in Figure 1. The measurements can be find in Table 1.

Table 1. The main specifications of the bodies

Type of plough	Marks of moldboard	h (mm)	h_{max} (mm)	l_{max} (mm)	b (mm)	b_{max} (mm)	γ_0 (degree)	α_0 (degree)	α_1 (degree)	φ_1 (degree)
1. SZABÓ	GEF-35	-	-	-	350	-	42	-	-	-
2. RWR	SRP-347	340	565	970	350	575	39	20	31	49
3. LOS	P 61692	430	435	910	300	520	37	24	-	48
4. HOWARD	SP4	540	540	590	560	560	45	-	-	-

To determine the characteristic curves of moldboard we used the modified Söhne slit-light method. We projected a slit-net of light onto plough body that were painted white and recorded the reflected light trace photographically. The slit-net vas projected vertically from two directions as the Figure 2. shows. This technique provides the characteristic curves of the change of cutting angle (δ) and turning angle (β) respectively. The evaluation of these curves can be useful for comparing shapes and for defining types and suitability of the special bodies.

RESULTS AND DISCUSSION

Szabó-type roller plough.

Watching and evaluating the curves (Figures 3-4), represent the intersection of the vertical planes and the surface being described can be say the tested moldboard (the shin and the rollers together) looks like semi-digger type. If it is true, the succesful turning effect of roller-type moldboard is understandable. The rolling rubber covered rollers can help finish the turning effect which is started by the share and the shin. This is an interesting finding because in the late sixties and seventies there were a lot of debate on the roller plough of which compering test had been made with cylindrical moldboard insted of semi digger type one.

Slat-type moldboard

The situation of slat-type moldboard is similar than was with Szabó-type roller plough. The first look to the body couldn't give a right impression because the missing parts of the moldboard make difficult to imagine the original shape.

Evaluating the curves (Figures 5-6) we determine the shape as an universal type. The results of the field test gave similar measuremnets with slat-type and the original moldboard. There was not any measureable differencies beetwen the draft requirements of the compared bodies. The only advantage of slat-moldboard was the smaller stickiness in the wet sticky soil due to the bigger normal pressure on the surface of the slats.

Losange-type moldboard

Watching the curves of body (Figure 7-8) we can see special thing on the furrow wall side only. Both the cutting and turning curves show the characters of a cylindrical moldboard. As well known the moldboard like this has poor turning effect so it can well suite only to sandy and sandy-loam soil, with no big amount residue on the surface.

The result of field test didn't confirm the advantages of Losange moldboard was generally reported earlier. The only one advantage of the body we met in our research was the wide, bended furrow which doesn't make damage in tires and decreases the compaction of ploughed land. Because of a wide, bended furrow can be made other and cheaper methods, the losange body didn't become popular in our country.

Square-type moldboard

The greet succes of swing (square) plough at the international fairs has arisen a question, is it a new tillage tool really or is it a modification of moldboard plough? Reading the technical papers and agricultural machinery magazine we could meet the entirely different opinions of the authentic people. Some people says it is a dozer-blade, other says classical plough body.

Trying to give the right answer we used the slit-light method to make a comparison between the square- and a conventional body. Evaluating the changes of the cutting and turning angles on the recorded photograph (Figure 9-10) we found that the moldboard of the square body is a typical cylindrical type. Due to the theory of swing (square) plough - namely the symmetrical construction - the charasterictic curves on both side of the moldboard are the same. It means that the path of soil doesn't follow the shape of the moldboard wing-part causing a turbulance in the moving furrow-slice. The short, symmetrical moldboard has a lot of turning trouble on clay soil where the furrow-slice doesn't break up and specially in the case of heavy residue covered land.

Considering that we haven't enough information from this brand new tillage tools and as we know there are some new developtment on it, the research work shouldn't be finished.

CONCLUSION

The measurements and the results of our research confirm us, that the idea of using a renewed version of slit-light technique to evaluate and identify the special moldboards is useful. Using the recorded cutting and turning characterictic curves we are able to define the shape of moldboard, to identify the type of moldboard and to classify the special bodies by their climatic and soil condition suitability.

Based on the early-mentioned results and our practice, the application field of the tested special bodies are the next:

- Szabó-type roller plough: sandy, loamy and good condition clay soil with average residue.
- Slat-type moldboard: same application field as the original moldboard from it was made, but with higher soil moisture.
- Losange-type moldboard: loamy and good condition clay soil with small residue.
- Square-type moldboard: sandy and loamy soil with average residue.

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Figure 1. Marks of the specifications
(φ_1 = angle at b_{max})

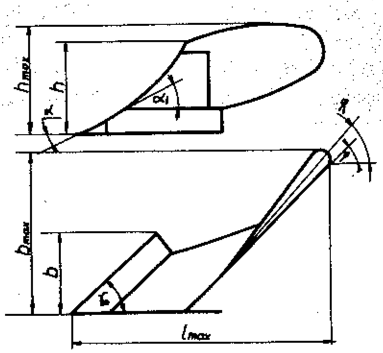


Figure 2. Scheme of the slit-light method
(Marks: 1,2,3,4 positions of the
camera and projector repectively)

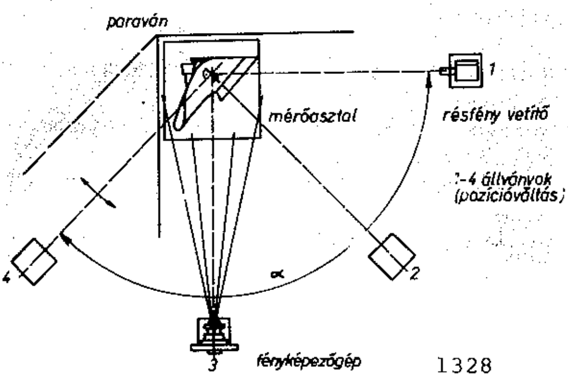


Figure 3. The cutting curves of Szabó-type moldboard

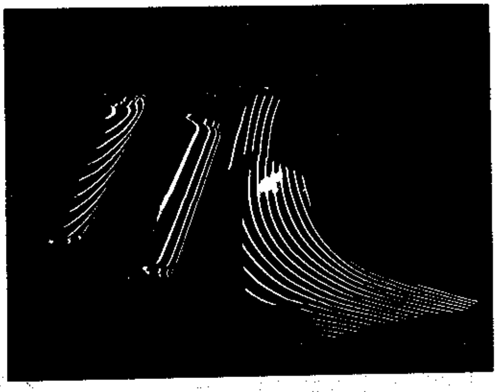


Figure 4. The turning curves of Szabó-type moldboard

Figure 5. The cutting curves of slat-type moldboard

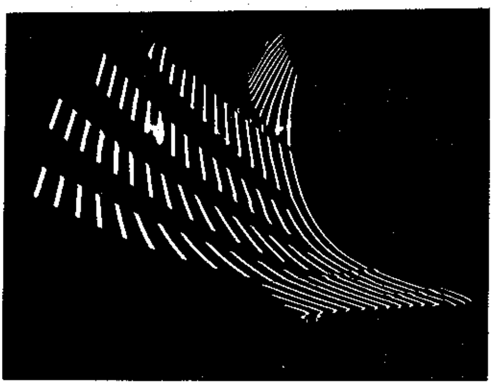


Figure 6. The turning curves of slat-type moldboard

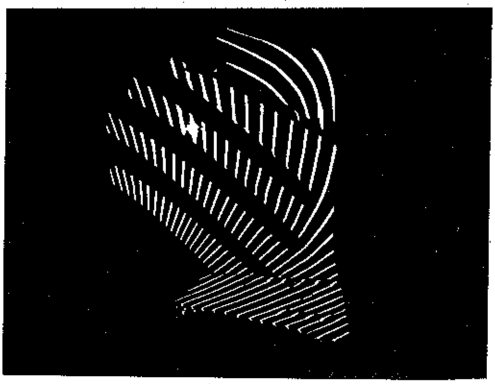


Figure 7. The cutting curves of losange-type moldboard

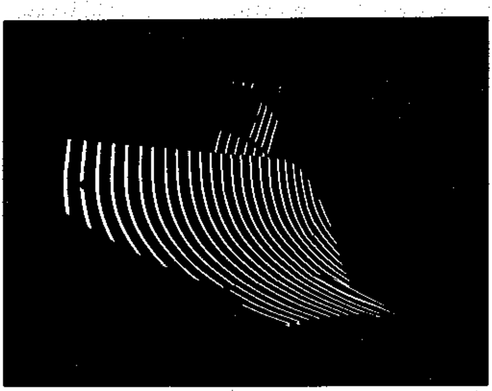


Figure 8. The turning curves of losange-type moldboard

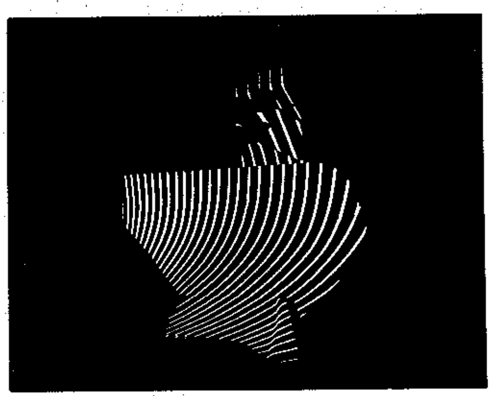


Figure 9. The cutting curves of square-type moldboard

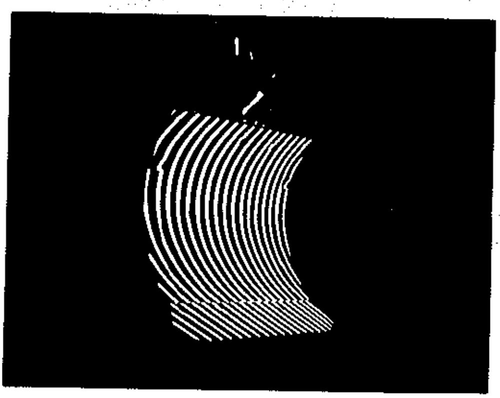
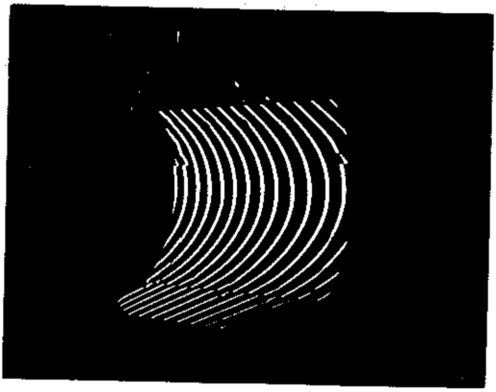


Figure 10. The turning curves of square-type moldboard



PLOWS TO IMPROVE PLANOSOL (BAI JIANG TU) SOLUM

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ABSTRACT

With field cultivation tests by Zhao and soil investigations by the author, one to one mixing of the second (Aw) and third (B) horizons was conducted to improve planosol solum leaving the first (Ap) horizon undisturbed. This paper deals with basic soil bin tests of soil mixing with half size model plows.

It was found that standing up and dropping down plows can be practically used in the field but that folding up plow is not practically used because the furrow slices did not move smoothly on the moldboard.

INTRODUCTION

Planosol solum distributes widely in the Shanjiang plain of Heilongjiang province, the Peoples Republic of China near the border of Russia and is a low yield soil. Fig. 1 shows the planosol solum of a cultivated field at 853 farm in Hosei district. The first horizon (Ap) is humic soil which is suitable for plant growth and has a thickness of about 200 mm. The second horizon (Aw) is lessivage soil which is dense and non–permeable and has a thickness of about 200 mm. The third horizon (B) below about 400 mm depth is diluvial heavy clay[1]. With the non–permeable Aw horizon, plants suffer in drought and with excess moisture. The soil hardness of the Aw horizon is more than 2.5 MPa (30 deg. corn angle, 20 mm base diameter) and the roots of plants cannot penetrate, as well as soil micro–organisms cannot live under the Aw horizon[3]. Because of the shallow top soil of the Ap horizon, forests do not develop and only shrubs survive in the hills and the fields in flat areas suffer from low yields.

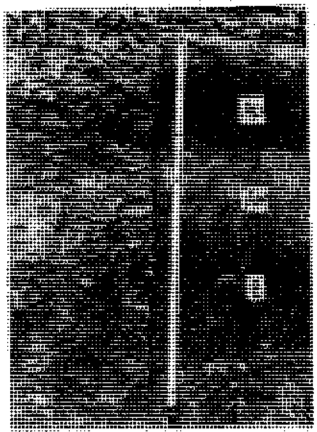
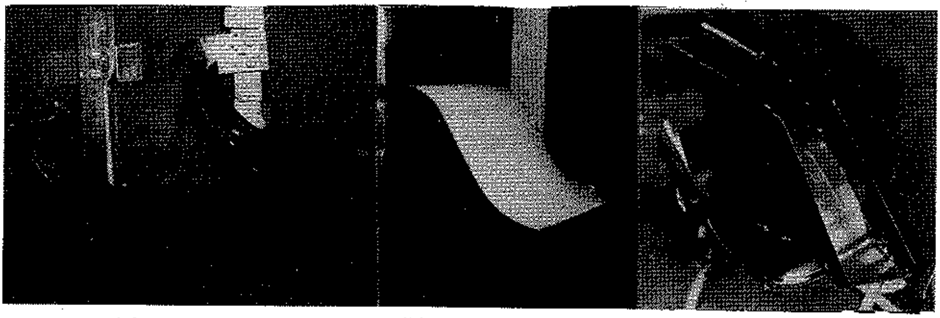


Fig. 1 Typical planosol (Bai Jiang Tu) solum at 853 Farm, China

This paper uses Zhao's field tests[3] and the author's investigations[4] to consider how to mix the Aw and B horizons in 1 to 1 ratios underground leaving the Ap horizon undisturbed. This mixing can be achieved by plows of a high operating efficiency for extremely wide areas of planosol solume. The basic soil bin tests were first conducted with three kinds of 1/2 scale model plows and an optimum plow shape was determined.

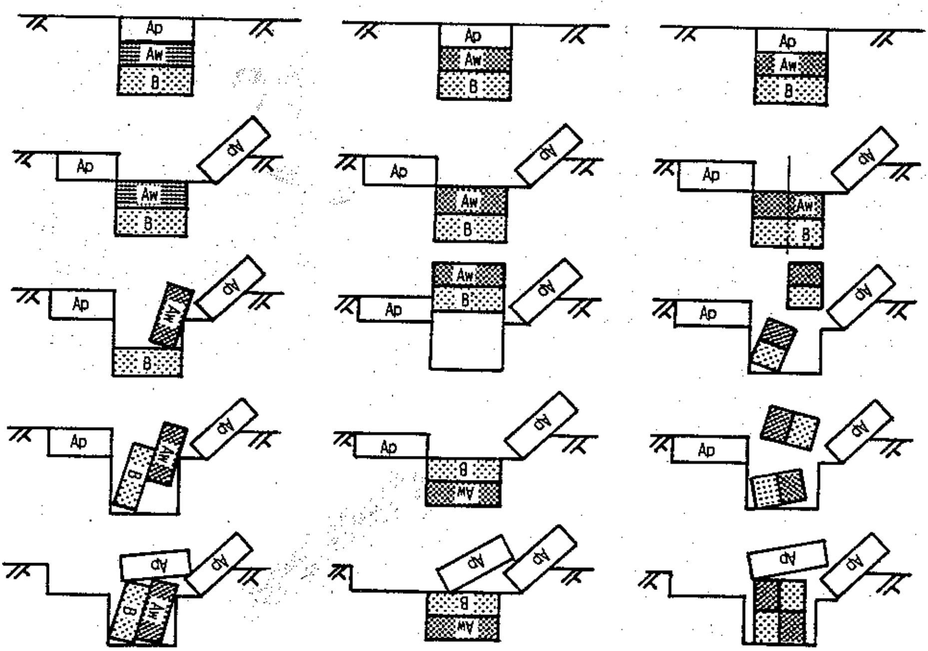
METHODS TO MIX THE AW AND B HORIZONS

The following three methods were tried here. The first is new and consists of 3 plows as shown in Figs.2(a) and 3(a) which refers to the method with volcanic ash[5]. When only No.3 plow operates, removing No.1 and 2 plows, the Ap horizon (0–200 mm) is tilled, Fig.3(a)–2 is obtained and then setting the No.1 and 2 plows, the 3 plows operate and the furrow slice of Aw horizon (200–400 mm) is stood up, turned 90 deg., in a furrow as in Fig.3(a)–3. The following No.2 plow tills the B horizon (400–600 mm) standing up the furrow slice achieving Fig.3(a)–4 (hereafter called the standing up type). The blackland bottom of the No.3 plow following after the two plows, tills the Ap horizon (0–200 mm) of the next furrow and inverts the furrow slice on the mixed Aw and B horizons (Fig.3(a)–5).



(a) Standing up type (b) Dropping down type (c) Folding up type

Fig. 2 Experimental plows (1/2 scall models)



(a) Standing up type M_x=0.322, T_{rB}=0.5

(b) Dropping down type M_x=0.322, T_{rB}=1.0

(c) Folding up type M_x=0.566, T_{rB}=0.5

Fig. 3 Schematic diagram of mixing Aw and B horizons

The second method is a combination of two plows as shown in Figs. 2(b) and 3(b). The No.1 plow of Fig.2(b) tills the Aw and B horizons together and raises them on the moldboard. Here the lower B slice is compressed on the sloped moldboard and the upper Aw slice drops down first and an invertion of Aw and B is obtained as shown in Fig.3(b)-4 (hereafter, called the dropping down type). Following, a blackland bottom plow tills the next Ap horizon which covers the inverted soil as above.

The third method is a combination of two plows as shown in Figs.2(c) and 3(c). The plow in Fig.3(c) tills the right furrow slice after cutting the furrow slice at the center by a colter as shown in Fig 3(c)-2 and raises it 400 mm (200 mm in the model tests). Meanwhile, the left furrow slice is turned down to the right at 90 deg. as shown in Fig 3(c)-3 and then the right furrow slice is turned down to the left at 90 deg. (Fig.3(c)-4) (hereafter called the folding up type). This soil turning must be done in the furrow and the center of gyration of the furrow slices must be outside as mentioned by Kamide[6]. Therefore, a side pressure board is fixed perpendicularly to the moldboard as shown in Fig.2(c) and the furrow slices are moved outside by transferring this crossline. A following black bottom plow tills the next Ap horizon and covers on it as in the other methods.

METHOD

Laboratory plow tests were conducted in a movable soil bin (530 mm high, 1800 mm long, 500 mm wide). A soil bin speed of 54 mm/s was used for all tests. This speed was slow compared with plow operation in the field, but the capacity of the soil bin drive system was limited to this speed. The horizontal (F_x) force (draught), vertical (F_z) force, and monents on the plow could be measured by the Γ beam.

Table 1 Mechanical properties of pseudogley soil and planosol solume

Soil	Moisture content w %d.b	Cohesion c MPa	Angle of internal friction ϕ deg.	Adhesion c' MPa	Angle of soil-metal friction δ deg.	Wet bulk density ρ kg/m^3	Plastic limit PL %d.b	Liquid limit LL %d.b
Pse.	21.5	0.0178	49.0	0.0023	16.3	2187	23.7	34.6
Pse.	37.5	0.0373	29.4	0.0049	10.1	2438	23.7	34.6
Pla. Ap	33.4	0.0407	36.8	0.0045	7.7	2100	28.2	43.4
Pla. Aw	25.8	0.0776	36.3	0.0057	16.4	2387	25.0	34.3
Pla. B	31.6	0.0625	42.7	0.0066	17.2	2050	37.0	53.8

The soil in the soil bin was pseudogley soil which is a Japanese heavy clay. Soil moisture was controlled at about 22%, near the plastic limit, and 38%, near the liquid limit. The mechanical properties of pseudogley soil and planosol solum are shown in Table 1. Cohesion of planosol solum is higher than pseudogley soil, especially that of the Aw horizon is extremely large. The 200 mm deep soil was prepared by compacting 100 mm layers to a hardness of 0.6 MPa on Yamanaka's hardness tester scale. The soils in this study were all disturbed samples. Plows in Fig.2 are all 1/2 scall models.

DEFINITION OF MIXING RATE

In this study, the ground refuse of buck wheat was mixed in the Aw horizon to make it white, and sewage sludge was mixed in the B horizon to make it black. The ground refuse of buck wheat contains white seed husks which do not dissolve in water and even moist soil can be kept white. The rate of soil mixing was determined by a photographic analysis of soil sections after plowing.

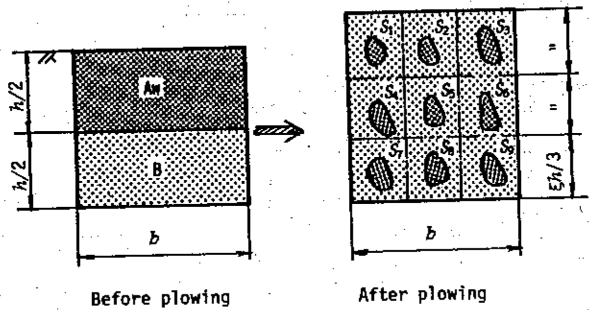


Fig. 4 Deffinition of soil mixing and transfer rates

In this study, only the mixing of the Aw and B horizons is discussed because of the model plow tests in the soil bin and the blackland bottom plow to till the Ap horizon in Fig.3 is not considered. In Fig.4, the left horizons before plowing are mixed and expanded after plowing and a new right horizon is obtained. The mixing of powder is suitably expressed by the variance of samples established in powder technology. To apply this method to soil, the soil section after plowing of Fig.4 (right) is divided into nine and the variance in the density of the Aw soil of nine soil samples is determined. Here the mixing rate M_x is defined as :

$$M_x = 1 - (\sigma/\sigma_0)^2 = 1 - \frac{4}{9}\sum_{i=1}^{9}\left(\frac{9S_i}{b\xi h} - 0.5\right)^2 \tag{1}$$

and defined the transfer rate T_{rB}, which shows how much the Aw horizon is transfered into the lower B horizon in Fig.4 (right), as:

$$T_{rB} = \frac{(S_4+S_5+S_6)+2(S_7+S_8+S_9)}{b\xi h} \tag{2}$$

where, M_x is mixing rate [(no mixing) $0 \le M_x \le 1$ (perfect mixing)], σ is variance in Aw density after plowing, σ_0 is basic variance in Aw density before plowing, S_i is area of Aw at each soil sample (i=1–9), mm^2, ξ is soil expansion rate after plowing (measured), b is operational width, mm, h is operational depth, mm, T_{rB} is transfer rate [(no transfer) $0 \le T_{rB} \le 1$ (perfect transfer)]

Therefore, for optimum soil mixing, the mixing rate M_x of Eqn(3) should be 1 and the transfer rate T_{rB} of Eqn(4) should be 0.5.

RESULTS AND DISCUSSION

Draught and suction

Fig.5 shows draught (F_x) and suction (F_z) of four kinds of plows with 22% and 38% soil moisture. The F_x and F_z of all plows with 38% soil moisture were larger than with 22% soil moisture. This is because the cohesion of pseudogley soil at 38% soil moisture is larger than 22% as shown in Table 1.

In Fig.5(b), the draught of the standing up type was minimum and the next was the dropping down type A with a draught about 500 N larger than the standing up type. The draughts of both plows were steady at both 22% and 38% soil moistures. However, the draughts of the dropping down type B and folding type varied widely. This was because the soil did not move smoothly on the plows but clogged in front of the plows and draught gradually increased. One weakness of the folding type is that soil crumbling took place because the center of gyration of the furrow slices must be moved by the force of the pressure board. Fig.5(a) shows the so-called suctions (downward force) which was not negative for any plow.

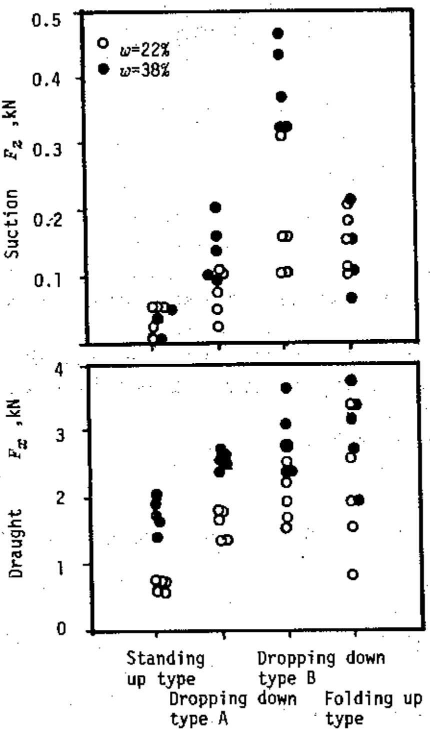


Fig. 5 Draught and suction of tested plows

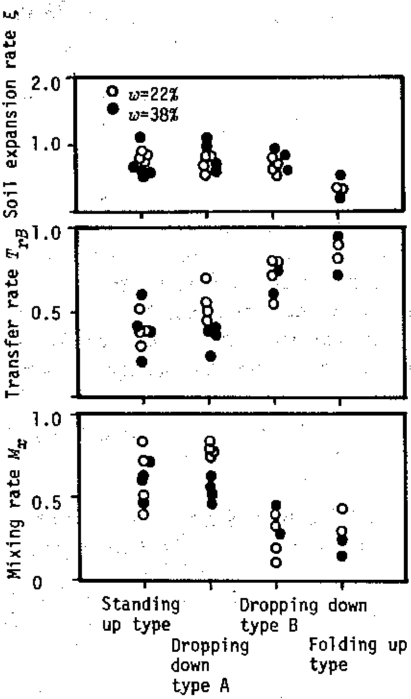


Fig. 6 Soil expansion, mixing and transfer rates

Mixing and transfer rates

Fig.6 shows soil expansion, mixing and transfer rates of the four plows. With the standing up type, the mixing rate M_x was 0.4–0.8, and the transfer rate T_{rB} was 0.3–0.6 regardless of soil moisture, because of the plow configulation. If two furrow slices stand up perfectly such as in Fig.3(a)–5, M_x=0.332, T_{rB}=0.5 from Eqns(1), (2), the measured M_x is larger than the predicted M_x because more complicated soil movement takes place on an actual plow.

With the dropping down type A, M_x and T_{rB} with 22% soil moisture were larger than with 38%, which was affected by soil moisture; M_x and T_{rB} were not smaller than the standing up type even at 38% soil moisture. If the furrow slices turn perfectly upside down such as Fig.3(b)–5, M_x=0.332 and T_{rB}=1.0.

With the dropping down type B and the folding up type, soil did not flow steadily on the plow and M_x was extremely small. Only the upper Aw horizon was thrown rearward, leaving the lower B horizon, and T_{rB} is large. The soil expansion rate ξ is also small because not all soil was thrown rearward.

Figs.5 and 6 show that the standing up type can be put to practical field use because of small draught and good mixing rates regardless of soil moisture. However, the mixing rate did not reach one because with the plow configuration, the furrow slices were stood up and arranged lengthways as shown in Fig.6(a).

The dropping down type can also be practically used because of the simple plow configulation. It is necessary to determine the best plow height and moldboard angle where a smaller draught and better soil mixing can be obtained.

The folding up type can not be practically used. In Fig.3(c), if the right and left furrow slices are perfectly folded up, M_x=0.556 and T_{rB}=0.5 there is ideal soil mixing. We must determine how to transfer the soil on the plow without it breaking down.

CONCLUSIONS

1. Cohesion of planosol solum is higher than pseudogley soil, especially that of the Aw horizon is extremely large.
2. The draught of the standing up type was minimum and the next was the dropping down type A with a draught about 500 N larger than the standing up type. The draughts of both plows were steady at both 22% and 38% soil moistures.
3. The draughts of the dropping down type B and folding type varied widely. This was because the soil did not move smoothly on the plows but clogged in front of the plows and draught gradually increased.
4. With the standing up type, the mixing rate M_x was 0.4–0.8, and the transfer rate T_{rB} was 0.3–0.6 regardless of soil moisture, because of the plow configulation.
5. With the dropping down type A, M_x and T_{rB} with 22% soil moisture were larger than with 38%, which was affected by soil moisture.
6. With the dropping down type B and the folding up type, soil did not flow steadily on the plow and M_x was extremely small. Only the upper Aw horizon was thrown rearward, leaving the lower B horizon, and T_{rB} is large. The soil expansion rate ξ is also small because not all soil was thrown rearward.

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ON THE INFLUENCE OF THE ANCIENT TOOLS TO THE ARABLE SOIL ENVIRONMENT IN CHINA

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ABSTRACT

This paper discusses the influence of the ancient Chinese tools and tillage on the soil environment in China. The points are as follows:
Discuss the importance of tools in soil tillage. It should be pointed out that studying the tools is a good way to understand traditional Chinese tillage theory and technique.
Clarify the influence of development of tools on the soil environment during several thousand years, with the stress on the important roles of tools and the ways of soil tillage in keeping soil water and nurture in Chinese history, pointed out that the development of traditional Chinese tools promoted the amelioration of the soil environment.
These excellent soil tillage techniques are still influencing today's agriculture in China.

INTRODUCTION

China, as a country with an ancient civilization, has a long history of agriculture. In its traditional agricultural production, soil tillage is considered the most important step in agricultural production. In the existing earliest Chinese agricultural document "Lu Shi Chun Qiu", the concept of "tillage theory" was first mentioned, giving a comparatively systematic exposition of the tillage theory(1). In the famous works of ancient agriculture "Qi Min Yao Shu", soil tillage is the first chapter and it was regarded as the most important part in agricultural activities(2).

Soil tillage must depend on farming tools, different farming tools determine different structures of tillage layers, and have important influence upon the environment of soil tillage. In the ancient Chinese agricultural production chain which includes cultivating, sowing, intertilling, harvesting and grain processing, different farm tools came into being according to the production needs. The tools of soil tillage took an outstanding position and had great influence on the formation of cropping system and soil management in ancient China, and they played an important role in the traditional intensive cultivation. They are also the essence of historical heritage of ancient agricultural science of human being.

MATERIALS AND METHODS

All the references consulted in this paper embrace four aspects. The first is the Chinese agricultural classics, which takes up a large proportion in all the Chinese classics. According to the statistics, there are 643 kinds of ancient agricultural books, about 300 kinds of which handed down to the present day, and this is surprising in the world(3). Many of these agricultural books are about soil tillage and agricultural tools. The second is archaeological materials. China has made great achievements in unearthed cultural relics. Many stone, bronze and iron farm tools have been unearthed. Many ploughing frescoes, stone inscriptions and decorated bricks have been discovered. They are precious materials in studying the soil tillage. The third is the materials from investigation on modern agriculture. The traditional way of the tillage and farm tools are still kept in many areas of China, which provide us with many practical materials. The fourth is the experimental data. Chinese scientists once made a summary of the way of tillage and conducted a research test on the good way of tillage——a tillage layer with loose and compact soil microzones existing simultaneously (LCES), and gained thousands of data. This helps us to make further study on the intension of ancient tillage technique(4).

The methods we adopted are those of textual research with detailed historical documents, making a description and textual research and experiment, conducting a text on the fields on the way of tillage, thus having a further understanding of the ancient tillage.

RESULTS AND DISSCUSSION

Tools directly promoted the development of soil tillage technique and the change of soil environment. The development of the ancient tools of tillage in China and the soil tillage technique went through the following periods:

1. Neolithic Age—Western Zhou Dynasty (about 8000—771 BC).

The agriculture of China has a History of ten thousand years. In La Yi Hai, Gui Nang County, Qinghai Province in the Yellow River Valley, chipped intaglio waist stone axes, choppers, stone sadale—querns, stone rollers were unearthed(5), and in Er Mao Kou, Huai Ren County, Shanxi Province, chipped stone axes (some being polished at the blade), stone hoes and choppers were found(6). In Sha Yuan, Da Li County, Shaanxi Province, a small number of chipped stone axes were discovered(7). The tools unearthed in the above ruins prove that the primitive agriculture came into being. In the ruins of Xian Ren Dong, Wan Nian County, Jiangxi Province of the Yangtze River Basin, choppers, perforated stone implements were discovered, which shows the primitive agricuture(8). It is estimated that at that time the way of tillage—the slash-and-burn cultivation was adopted, that is, cutting down trees and weeds and setting fire to burn the grass on waste land.

In the period of the Neolithic Age(about 5000 BC), primitive agriculture took a step forward, entering the stage of spade—cultivation. In the ruins of Pei Li Gang Culture, Henan Province in the middle reaches of the Yellow River, a large number of stone spades, sickles and stonemills were unearthed(9). In the ruins of Ci Shang Culture of Hebei Province, similar type of tools were unearthed with millets(10). Hemudu Culture of Yu Yao County, Zhejiang Province represents the primitive agriculture of the Yangtze River Basin, because a large number of boned spades, stone axes, and stone spades were found there, accompanied with rice(11). In the middle and later periods of the Neolithic Age, Yangshao Culture (about 4000 BC) and Longshan Culture (about 3000 BC) showed up in the Yellow River Valley. A lot of polished stone axes, stone spades, stone hoes and other farm tools as well as a small mumber of stone ards were unearthed. At the same period, in the Yangtze River Basin, similar type of implements were unearthed, among which stone ards unearthed in Tai Hu area has special characteristics (12). At the same time, the wooden tools like "*Leisi*" (like spade) also played an important role.

In Xia Dynasty (2100—1600 BC), Shang Dynasty (1600—1100 BC), Western Zhou Dynasty (1100—771 BC), bronzed tools like axes, spades and ploughs came into use, but stone tools and wooden implements still played a leading role in farming, agricultural prduction was in the stage of developed spade cultivation.

In the early period of primitive agriculture, people sowed in holes on the uncultivated land with sharp stick after setting fire to turn grass on waste land. It is so—called "No—tillage". Since Pei Li Gang Culture, farm tools, such as stone spades, hoes, adzes had been widely used. After the soil was cultivated, it became soft, thus, its property of being pervious to light and ventilation had been greatly improved, which provides a favorable condition for crops to grow. But wooden and stone tools at that time were still heavy, they could not dig the soil to the deep layer. The output of the crops was very low. The soil prostration was in high frequency. So the main cultivation methods adopted was abandoning waste land.

2. The Spring and Autumn Period—the Han Dynasty (770 BC—220 AD)

Since the Spring and Autumn Period, iron implements took the place of the stone and wooden implements, which marked the great advance of production implements. In addition, ox—ploughing began to be spread, the tillage theory began to take shape.

As ironed implements were widely used, deep ploughing and intertillage got more attention and were widely spread, they had been recorded by Guo Yu (13), Guan Zi (14), Zhuang Zi (15) etc. Deep ploughing, crushing soil many times play an important role in soil tillage. they help improve the physical conditions for the system of the plant roots and microorganism. Lu Bu—wei stated the depth and function of the deep ploughing. He said that the depth of ploughing should touch the moisture in soil, and the field was not only ploughed five times, but also hoed five times. He also mentioned hoeing's function—hoeing up weeds and killing insects (1).

Throught all the unearthed tools of the Warring States Period, such as hoes, "leisi", and spades (16), We known that they could satisfy the demands of deep ploughing and intertillage.

In Han Dynasty, Fan Sheng—zhi regarded early intertillage as the basis of cultivation (17). Intertillage can hoe up weeds to avoid weeds occupying the fields, and can soften the surface of soil, break up the hardened impervious soil to increase the aeration of the soil. When the soil is dry, intertillage can cut off the capillary of the surface soil, so as to prevent water from evaporating. When the soil is too wet, it can soften the soil so as to increase the evaporation of water, and it can meet the needs of dry soil in the Yellow River Valley. Intertillage is one of the most important parts in traditional Chinese intensive and meticulous agriculture.

The popularity of the ox—ploughing and ridge culture turned the period into an important stage of the soil tillage.

The ards were found in the Neolithic age in China, ox—ploughing was recorded in Shang Dynasty(1600—1100 BC). Since the Warring States Period(770—476) the ox—ploughing had spread(11), and it provided a good condition for ridge culture. The ridge culture was formed in the Western Zhou Dynasty (1100—770 BC). Lu Bu—wei expounded them systematically, and wrote that the "crops should be planted in furrows in a higher field,and on ridges in a lower field" (1),so that people could prevent drought and waterlogging . Because they used the no—mouldboard plough(16), the arable layer structure was one type of LCES in the Warring States Period. In the Western Han Dynasty, Zhao Guo spreaded "the rotation of fields". A piece of field should be divided into several ridges and furrows,the crops were planted in the furrows and the positions of the ridges and furrows should be interchanged every year. At the same time, he spread "*ou* plough" for necessary tool(12). In the center place where "the rotation of the fields" was spread, a type of plough of Han Dynasty was unearthed, on the tongue—shaped iron share, an isosceles triangle—moulboad was fixed which could plough the soil to both sides, and it made two ridges and one furrow,(16), it was just the plough for "the rotation of the fields". Because there were immature soil left untouched under the ridges, they belonged to part—cultivation, and the tillage layer was LCES(4).

The structure of soil tillage layer has great superiority. The first is that it suit the needs of preserving the moisture of the soil. Because of part—cultivation, less soil would be moved, so the water in the soil would evaporate slowly. And at the same time, the crops were planted in the ditches, they could absorb water from the deeper soil. And as for the soil structure of LCES, the part of "loose" could absorb more water as a "cistern"; and the part of "compact" could transport more water as a "water pump". That was an undertaking for fighting drought. The second is that the soil structure could regulate and improve the conditions of soil nutrient for crops. The part of the "loose"could get more oxygen, light and water, so it was good for soil's mineralization. The part of "compact" is opposite to the part of "loose", but it is good for soil's humus, their superiority can be exchanged in the soil structure, and it is advantageous to the crops in this soil environment. Since 1965, Chinese scientists have made a systematic study of the soil structure, their experiment shows that by comparison of different types of tillage layers , this soil structure can make an optimal moisture and nutrient condition of the cultivated soil(4).

3. Wei, Jin and Southern and Northern Dynasties —Sui and Tang Dynasties(220—907 AD)

Complete cultivation was the characteristic of this period. The mouldboad which could plough the soil on one's side was invented in the Western Han Dynasty(206 BC—24 AD)(12). This mouldboad—plough was used extensively since Wei and Jing Dynasties (220—420 AD). Some mouldboad—ploughs were found in Mian Chi County,Henan Province(18), there was one mouldboad sloping down to the right side. This shape of plough could plough all the fields, and did not leave immature soil. This method of complete cultivation formed an "upper—loose and lower—compact" soil structure. It just suited the demand of intensive ploughing proposed by Jia Si—xie(2). The complete cultivation turned a large amount of soil over, so the water evaporated easily from the soil, and it would lose the moisture in the soil. How to preserve the moisture in the soil in the dry area of the Yellow River Valley is a difficult problem. Precisely because of this, the ancient people invented a system of *"geng—ba—mo"* (ploughing—harrowing—smashing). The *"ba"* (harrowing) was found in Wei and Jing Dynasties, but the *"mo"* was recorded in Eastern Han Dynasty (25—220 AD) (18). The *"mo"* was made of twigs of chaste trees or willow twigs, it could pull, rub and smash the soil after the harrowing (2). The loess was a vertical structure, the moisture evaporated easily from the capillary in the soil. Ploughing, harrowing and *"mo"* could cut up the capillary, stop the evaporation of the moisture, and also form a layer of heat preservation, thus creating a good condition for plants. The system of *"geng—ba—mo"* showed the maturity of the soil cultivation technique in North China, it still has a deep influence on the modern agriculture in China.

4. Song—Qing Dynasties (960—1911 AD)

Since the Northern Song Dynasty (960—1127 AD), people got a clear understanding of the harrowing and *"mo"*, and stressed their important roles in the soil tillage in North China (19).

In South China, the soil tillage got a new development in that period. The *"chao"* was used for the paddy field after ploughing and harrowing in South China (19). The *"chao"* was a paddy field harrow, it could produce the mud, and made the mud with fertilizer together, thus creating a good condition for rice (19). The system of *"geng—ba—chao"* showed the maturity of the soil cultivation technique in South China.

CONCLUSION

The soil tillage was always regarded as the most important factor for the agricutural production in ancient China. The tools such as ploughs, harrows, *"moes"* and hoes promoted the development of the soil tillage ways, and promoted the amelioration of the soil environment. They are the important parts of the traditional intensive cultivation in China.

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