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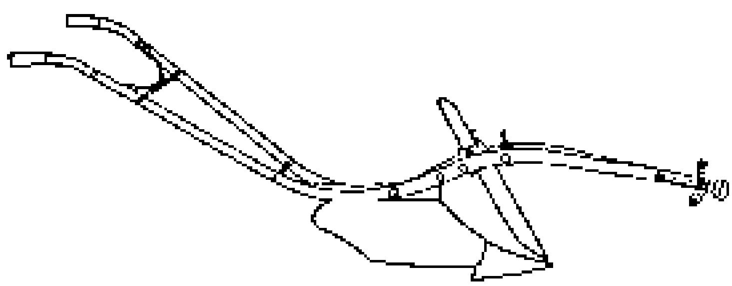

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Preface

A series of international soil tillage conferences have been organized in Western Europe during the post-war period, but it was not until at the 6th Conference held at Wageningen 1973 that the ISTRO was properly constituted. The regulations (next page) are a result of the extensive preparatory work done by Prof. Kuipers.

The record of the earlier conferences, of which the first 4 were arranged in connection with World Ploughing Contests, is as follows:

1955 at Uppsala, Sweden, organized by G. Torstensson

1958 at Stuttgart-Hohenheim, Western Germany, organized by Prof. H. Frese. The main theme was ploughing and papers were published in " Mitteilungen der Deutschen Landwirtschafts-Gesellschaft", Vol. 74, Heft 13, 1959.

1962 at Doorwerth, Netherlands, organized by Prof. H. Kuipers. The proceedings "The objectives of soil tillage" were published in "Netherlands Journal of Agricultural Science", Vol. 11, No. 2, Special Issue 1963, pp. 85-160.

1965 at Aas, Norway, organized by Mr. A. Njøs, under the supervision of the Scandinavian Agricultural Research Worker's Association (NJF). The proceedings "Characterization Problems in Soil Tillage" were published in the Swedish journal "Grundförbättring", Vol. 19, Division of Soil Management, Agricultural College of Sweden.

1970 at Silsoe, England, organized by Mr. N.J. Brown. The mimeographed proceedings "Tillage Research Methods" are available from N.J. Brown Esq., Physics Department, Rothamsted Experimental Station, Harpenden, Herts, England. (Price £1.25 inc. postage. Remittance made out to "N.J. Brown (Soil Tillage A/c)". If outside UK please pay in sterling through a London Bank).

1973 at Wageningen, Netherlands, organized by Prof. H. Kuipers. A mimeographed summary of papers is available.

As seen from the list above, the way of publishing the conference proceedings has varied, and is a matter of the organizer. To facilitate bibliographic notation, we include the proceedings of the present conference in our series of mimeographed reports. Most of these reports are available on request.

The papers submitted to us cover a wide area of soil tillage research, the main topics being tillage problems in ploughless farming systems, soil compaction and plants growth, and physical properties of soils and performance of tillage tools. The papers are published in alphabetical order.

We are indebted to the Ministry of Agriculture for the finacial aid and to the University of Uppsala, the Agricultural College of Sweden, the county agricultural boards and the different institutes and companies for the facilities provided. Finally we are grateful to all colleagues for the generous help in preparing the conference.

Reijo Heinonen — Chairman of the Board of ISTRO

Lennart Henriksson — Secretary of the Board of ISTRO

internationaal agrarisch centrum

INTERNATIONAL AGRICULTURAL CENTRE
CENTRE AGRICOLE INTERNATIONAL
INTERNATIONALES AGRAR ZENTRUM

Wageningen, September 27, 1973

Regulations of the International Soil Tillage Research Organization, accepted during the 6th Conference, September 25 - 27, 1973, at Wageningen, the Netherlands.

1. The objective of the International Soil Tillage Research Organization is to promote contacts between soil tillage research workers by initiating conferences and eventually by other means.

2. The Board of the organization is formed by the past, present and next president and two other members, who serve untill the next conference.

3. The president is in charge of the organization of the next conference. He chooses one of these other two members of the Board preferably in his own country, who will act as secretary of the I.S.T.R.O.

4. The fifth member of the Board is proposed by the Board or by participants of the conference. He may interchange his function with that of the next president, if that seems to be appropriate.

5. All participants of the conference can make proposals for election to fill vacancies in the Board and for changes in the Board.

6. All participants of the conference have the right of voting.

7. The president is free to organize the conference as seems to be appropriate and to cooperate with other organizations. He is responsible for informing the Board on his major activities.

8. If possible conferences should be held at least once every three years.

9. If the president is unable to organize the conference he consults the Board and the Board has the right to reorganize itself.

10. Members of the organization are participants of the conferences involved in tillage research and tillage research workers that apply for membership. All members are invited to conferences.

The Committee in charge of regulation proposals,

N.J. Brown (U.K.)

Dr. W. Czeratzki (BRD)

Prof.Dr. R. Heinonen (Sweden)

Prof.Ir. H. Kuipers (The Netherlands)

Prof.Dr. V. Mihalić (Yugoslavia)

The 7th Conference of the International Soil Tillage Research Organization, Sweden. 1976.

SEEDBED PREPARATION FOR OPTIMUM TEMPERATURE, MOISTURE, AERATION, AND MECHANICAL IMPEDANCE[a]

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ABSTRACT

A tillage method is presented for optimizing seedbed preparation by planting on the sides of sloped ridges. Temperature, moisture, aeration, and mechanical impedance effects are controlled by configuration and direction of the ridge and by the use and location of the seed row press wheels. The method hedges against either a wet or a dry spring after planting. Two years of results of replicated field tests on maize (Zea mays, L.) are presented. Faster emergence, higher stands, and statistically significant yield increases up to 1685 kg/ha are reported for the optimized method over conventional flat planting and top-of-ridge planting methods.

INTRODUCTION, THE TILLAGE SYSTEM

Four soil physical factors that govern plant growth are temperature, moisture, aeration, and mechanical impedance. Much work has been done observing and specifying the conditions necessary for plant growth, especially during germination and emergence. See S.J. Richards et al. (1952), p. 366, for temperature study; see L.A. Richards and Wadleigh (1952), pp. 214-217, for moisture study; see Wesseling and van Wijk (1957), pp. 466-468, for aeration study; see Phillips and Kirkham (1962) for mechanical impedance study; see Bowen and Coble (1967) for a study on limiting values of all four factors. Additional references and reviews are in Shaw (1952), Jacobson [see Bowen and Coble (1967) reference], Kirkham (1973), and Rykbost et al. (1975).

In this paper, we describe a seedbed preparation method intended to optimize soil temperature, soil moisture, and aeration, while providing low mechanical impedance for seedling growth. Our work has been done on maize (Zea mays, L.), the principal crop of the North Central part of the United States of America. The State of Iowa where this work was done, is 500 km west of Chicago, Illinois. Iowa has a subhumid climate, the precipitation averages 75 cm per year, and most of the precipitation occurs as rain in the growing season. Irrigation is not practiced. Planting of maize normally begins about the 1st to the 10th of May. In recent years, emphasis has been placed by Iowa's Agricultural Extension specialists on planting maize as early as possible. Early planting provides for a longer growing season if the soil is sufficiently warm. With the longer growing season, greater yields result.

Fig. 1 shows a sloped-ridge planting system that we used to increase

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[a]Journal Paper No. J-8428 of the Iowa Agriculture and Home Economics Experiment Station, Ames, Iowa. Projects No. 1888, 2086, and 1941.

[b]Research Associate, Distinguished Professor of Agronomy, and Professor of Agricultural Engineering, Iowa State University, Ames, Iowa.

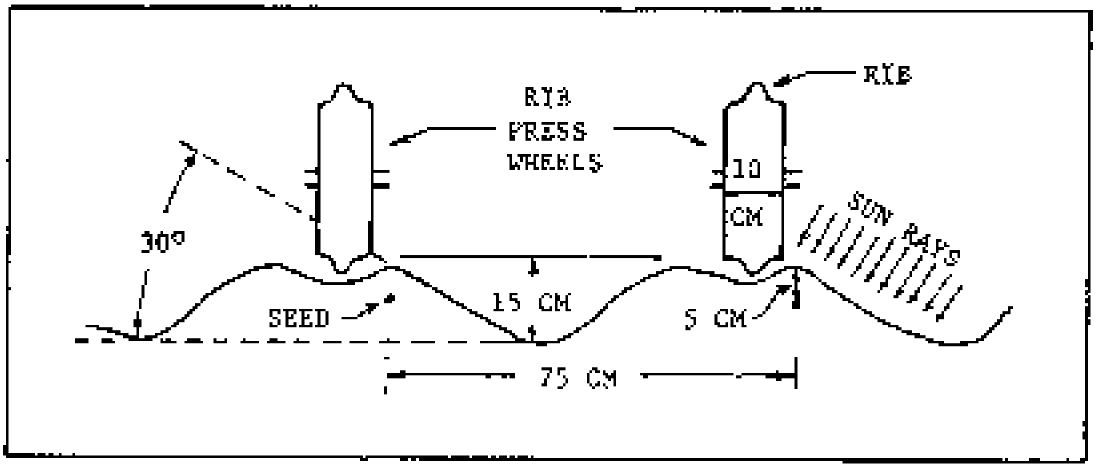

Fig. 1. Optimized Seedbed Planting System

soil temperature for early spring planting and to optimize soil moisture and aeration and provide low mechanical impedance. Seeds are planted on the south slopes of ridges that run in an east-to-west direction. The south slope is shown intercepting the sun's rays perpendicularly, which is the condition for maximum energy interception and soil warmth. The sun's angle to the horizontal was 60° at noon on April 18 and showed that the slope of the seedbed was best at 30° to the horizontal. The angle was measured by pointing one end of a rod towards the sun, the other end of the rod being fixed at the ground surface. No shadow was cast on the ground at a rod slope of 30° from the vertical. Tables of the sun's angles are available (Engel and Takle, 1979). The system of Fig. 1 has been designed to optimize soil moisture and aeration under the climatic extremes of both wet and dry springs. For a wet spring, the furrows provide drainage of excess water and needed aeration. The seeds are planted above the furrow bottoms so that the seed environment will not be waterlogged. For a dry spring, moisture must reach the seeds from below the planting depth, and our design uses compaction of the soil crumbs to provide better upward flow of capillary water to the seeds. In Fig. 1 are shown two rib press wheels 10 cm wide, which follow the tractor-drawn planter. These press wheels are shown upslope from the seeds. We also have tested the rib press wheels downslope from the seed row. Further, we have used a concave press wheel 15 cm wide directly over the seed row. Both press wheels are commercially available from the John Deere Company. The compaction by the rib press wheel is greater than that by the concave press wheel. Both compact the soil crumbs in the seedbed to enable easier capillary rise of subsurface water to the seeds in a dry spring and at the same time form a packed soil layer at the surface to reduce moisture loss by evaporation. The rib on the press wheel in Fig.1 makes a small, highly compacted furrow next to the seed row. During a short, high-intensity rain, this small furrow can collect water to provide needed moisture to the seeds in a dry spring. The furrow does not cause waterlogging around the seeds because good drainage is provided by the loose soil to the furrows on either side of the ridge. In our tillage system, we use no cultivation after planting; weed control is by chemical spraying. All operations are by tractor-drawn machinery, as in large-scale farming.

RESULTS AND DISCUSSION

We have obtained two years of field data for the sloped-ridge planting system of Fig. 1. The first year, 1974, we compared two variations of sloped-ridge planting with flat and top-of-ridge planting. Cross sections of the four treatments as actually measured in the

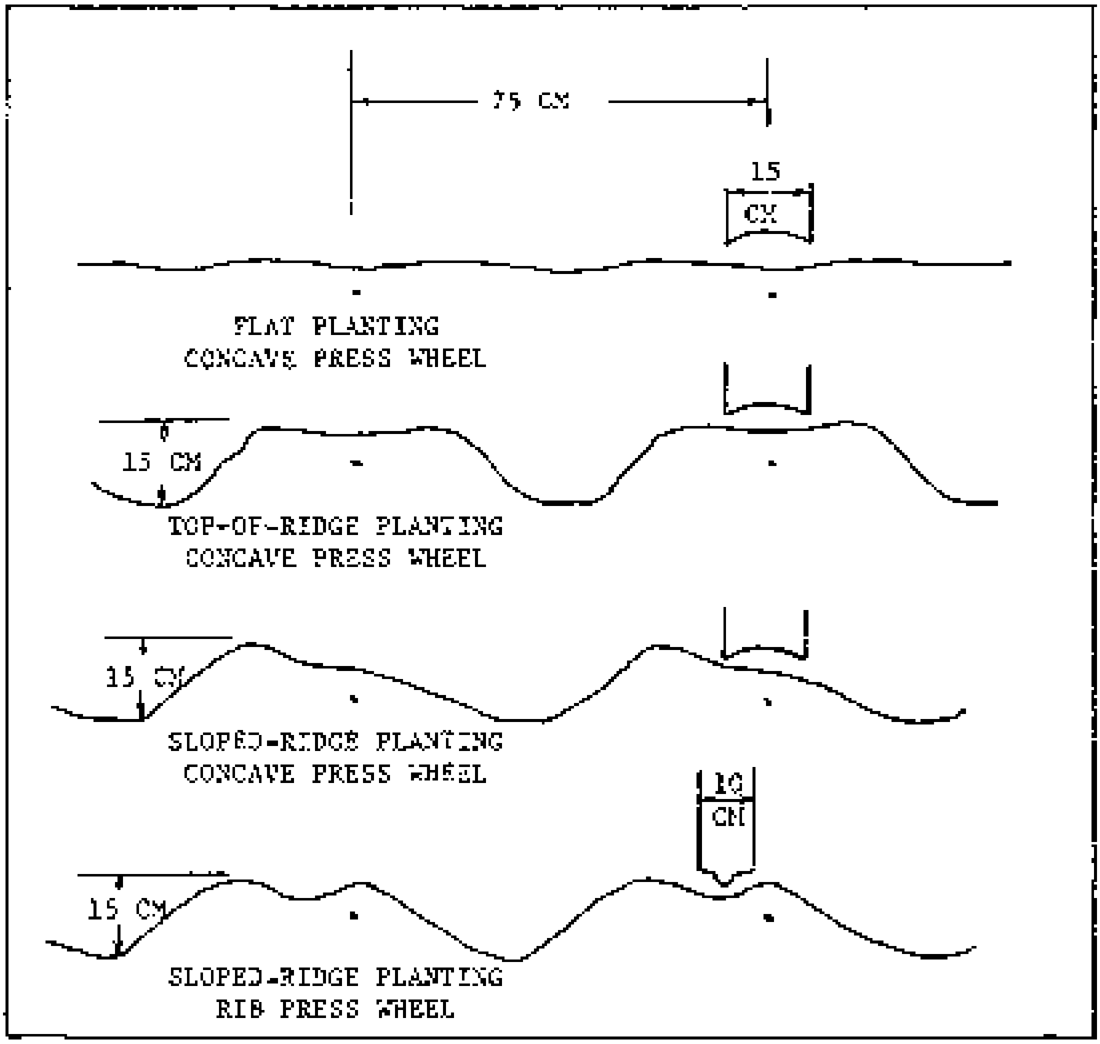

Fig. 2. Measured Cross Sections of Four Planting Treatments

field are shown in Fig. 2. Note that the concave press wheel was used over the seed row in three of the treatments. We planted six replicates of the four treatments in a statistical, randomized-block design. Each block was divided into two halves, one half planted April 18, the other half planted May 15, 1974. Each block was planted with all four treatments, four rows per treatment, and contained 16 rows. Rows were 30 m long and 75 cm apart. Maize seeds were planted 19 cm apart in the rows. Data were taken on the center two rows of each treatment to reduce edge effects of one treatment on another. The land was tile-drained, and the blocks were laid out so that the tile drainage would be equal for each block and for each four-row treatment.

In the following, designations such as SRCO and FNC are used for brevity, to describe treatments. These designations are given in Table I. (Note, SR = sloped ridge, CO = compaction over the seed row, etc.) In 1974, maize planted April 18 gave average yields for sloped-ridge planting (SRCO and SRCC) of 9303 and 9050 kg/ha; top-of-ridge planting (TRCO), of 8832 kg/ha; and flat planting (FCO), of 8502 kg/ha. The differences in yields between sloped-ridge planting and flat planting, 801 and 548 kg/ha, were statistically significant. Maize

Table I

1974 and 1975 Yields, Final Stands, and Emergence Rates for Maize on Sloped Ridges versus Other Planting Treatments

No.	Designation	Treatment Description	Yield (kg/ha) 1974 (Early)	Yield (kg/ha) 1974 (Late)	Yield (kg/ha) 1975	Final Stand (plants/ha) 1974 (Early)	Final Stand (plants/ha) 1974 (Late)	Final Stand (plants/ha) 1975	Emergence Rate (Days to reach 75% emergence) 1974 (Early)	Emergence Rate (Days to reach 75% emergence) 1974 (Late)	Emergence Rate (Days to reach 75% emergence) 1975
		Sloped-Ridge Planting									
1	SRCO	Concave press wheel compaction over seeds	9303a*	7994a	5613a	55055a	58843a	60437a	12	9.5	8
2	SRCU	Rib press wheel compaction upslope from seeds	9050a	7871a	5719ab	53540a	55294c	50391b	13	9.5	9
3	SRCD	Rib press wheel compaction downslope from seeds	---	---	6127ab	---	---	51826b	--	---	9
4	SRNC	No press wheel compaction	---	---	5199ab	---	---	48198b	--	---	10
		Top-of-Ridge Planting									
5	TRCO	Concave press wheel compaction over seeds	8832ab	7619a	3981cd	51786a	56490b	58563a	13	10	8
6	TRNC	No press wheel compaction	---	---	3582d	---	---	42378c	--	---	9.5
		Flat Planting									
7	FCO	Concave press wheel compaction over seeds	8502b	8058a	4898bc	44531b	57048b	56769a	13	10.5	7.5
8	FNC	No press wheel compaction	---	---	3907cd	---	---	40664c	--	---	10.5

*Means not sharing the same letter(a,b,c,d) differ from each other significantly at the 5% level of probability.

Notes:
1. Yields of maize are calculated at 15.5% moisture content.
2. Planting rate was 68888 seed/ha of Trojan TX113 (116 day) maize.
3. Fertilization was 168-168-168 kg/ha of N-P_2O_5-K_2O in 1974; 115-67-90 kg/ha in 1975.
4. Herbicide was 2.24 + 2.24 kg/ha of Atrazine and Alachlor in 1974; Atrazine and Cyanazine in 1975.

planted May 15 of that same year gave significantly lesser yields, 76?? to 8058 kg/ha, but with no significant differences among the four treatments. These results indicated, as expected, that earlier planting would give greater yields than later planting and that the warmth benefit for the early planted sloped ridges would increase yields. Evidence that the seed environment was actually warmer on the sloped ridges was obtained by inserting thermometers 7.5 cm deep along the seed rows and observing daily temperatures. Afternoon temperatures in early May in the sloped-ridge seed rows were about 1.5°C higher than the temperatures in the flat and top-of-ridge planted seed rows.

In 1974, rain conditions were very good during the germination and emergence periods for both plantings; 5.6 cm of rain fell April 20-22, and 8.3 cm fell May 16-18; consequently, we expected little moisture benefit on the sloped ridges versus the other treatments. Later rainfall was not heavy enough to cause waterlogging of the field, whether ridged or flat.

In 1975, wet field conditions precluded an early planting, so we included four new treatments with the four previously used and planted all eight treatments on May 13, the earliest date that conditions would permit. The four added treatments were:

1. Sloped-ridge planting, rib wheel downslope from seeds (SRCD)
2. Sloped-ridge planting, no press wheel (SRNC)
3. Top-of-ridge planting, no press wheel (TRNC)
4. Flat planting, no press wheel (FNC)

Yields were less in 1975 because we applied less fertilizer and because the herbicide treatment was less effective in controlling weeds because of a 15-day dry period after herbicide application. Dry conditions in July during silking probably also were a factor. We did obtain larger differences among treatment yields in 1975 than were found in 1974. SRCO and SRCU gave 5613 and 5719 kg/ha, TRCO gave 3981 kg/ha, and FCO gave 4898 kg/ha. SRCO and SRCU yields averaged together were significantly higher than either TRCO yields (1685 kg/ha difference), or FCO yields (768 kg/ha difference). Treatment SRCD, with the rib press wheel downslope from the seed row, gave the greatest yield, 6127 kg/ha, but this was not significantly different from the other sloped-ridge treatment yields. The treatments with no press wheel, SRNC, TRNC, and FNC, gave yields of 5199, 3582, and 3907 kg/ha, all of which were lower, but not significantly, than for corresponding treatments in which press wheels were used.

The large differences among yields for the treatments in 1975 may have been caused by the 15-day dry period immediately after planting. Measurements of soil moisture at seed depth 13 days after planting showed average moisture levels for all the treatments except FNC and TRNC to be between 25 and 27 percent on a dry-weight basis. The FNC and TRNC treatments, which gave the lowest yields and stands, averaged 21-and 22-percent moisture. The treatments compacted by the concave press wheel over the seed row, SRCO, TRCO, and FCO, gave faster emergence and significantly greater stands than the other treatments. SRCU and SRCD, with rib press wheel compaction to the sides of the seed rows, gave the greatest yields, but had significantly smaller stands than SRCO, TRCO, or FCO. We believe that the lack of compaction over the seeds for SRCU and SRCD could have retarded emergence and reduced stand early in the season because of moisture evaporation from the soil over the seeds but that, later in the season, the rib wheel compaction by the seed row provided better capillary flow of water to the plants from below and improved their yield.

The results presented indicate that seedbeds can be optimized to obtain higher yields by using sloped ridges and special compaction procedures. Press wheels were used for two purposes: 1) to promote capillary rise of moisture to the seeds in a dry spring and 2) to compact the surface layer of soil above the seeds for reduction of moisture loss in vapor form. To avoid droughtiness in sloped ridges, seeds were planted along the slope of the ridge, not at the top, but where the seeds would be above the bottoms of the drainage furrows.

From our results, we see a need to test the effect of compaction with the concave press wheel over the seeds, combined with compaction by the rib press wheel on one or both sides of the seeds. We believe this treatment will result in larger stands during dry springs. We intend also to investigate in further work the effects of different soil types, different crops, and planting in other than east-to-west directions because some fields cannot be planted east to west. We intend to obtain more data on temperature, moisture, aeration, and compaction of the soil. In the 1974 and 1975 plantings, we used several operations in making sloped ridges and had to run the planting equipment in only one direction. We are presently designing field equipment that will build ridges and plant in the same operation and that can operate in both directions in a field.

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SOIL COMPACTION AT SHALLOW DEPTHS AND CROP GROWTH

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ABSTRACT:

Effect of artificial compact layers at shallow depth on the growth and yield of irrigated crops (maize, wheat, pearl-millet, mustard, green gram and pigeon pea) investigated in field micro-plots on a loam soil has been reported. The crop growth and yields were adversely affected by a compact layer at shallow depth. To compensate the early set back in growth by compact layer, root and plant growth continued for longer time. The reduction in the yield of cereal crops was lesser than that of the other crops studied. The results suggest that the crops having tap root system are more susceptible to sub-surface compaction at shallow depths than cereals crops having fibrous root system.

INTRODUCTION:

Mechanical manipulation of soil forms a compact layer in root zone at shallow depth. In soils having such a compact layer, root growth and activity may be restricted as a result of mechanical impedence (Barley, 1963; Sangwan <u>et al</u>. 1974), insufficient aeration (Hickman <u>et al</u>. 1966) and reduced uptake of nutrients (Khanna <u>et al</u>. 1974; Frummel, 1975). The restricted root development may reduce plant growth and yield of crops. Under the situation, is it necessary to loose the dense sub-soil by deep ploughing to ensure maximum yield ?

At present, little progress has been made toward a quantitative evaluation of the allowable limits of compact layer at shallow depth for different crops. With this view, this study was undertaken to investigate the effect of a compact layer at shallow depth on the growth and yield of some irrigated crops.

MATERIALS AND METHODS:

Replicated field micro-plot experiments were conducted on Hissar loam soil (61% sand, 21% silt and 18% clay) from 1970 to 1974 with wheat, maize, pearl millet, mustard, green gram and pigeon pea. The pH and EC of 1:2 soil water suspension and extract were 8.4 and 0.6 mmhos/cm at 25°C, respectively. The soil retained 18 and 7 per cent moisture at 1/3rd and 15 bar, respectively. Three sub-surface compaction treatments were:

i). No compaction (bulk density 1.4/1.5 g/cm^3),

ii). Moderate compaction (1.6/1.7 g/cm^3), and

iii). Severe compaction (1.8/1.9 g/cm^3) as a 5 cm thin compact layer within 25 cm of root zone. The bulk density of normal soil was around 1.45 g/cm^3. The compact layer of desired bulk density was prepared manually with moist soil (17-18 per cent moisture) before sowing of crops.

Plant height was recorded on different dates as growth index. Root penetration was determined, either by placement of ^{32}P below the compact layer (Sangwan et al. 1974; Agarwal et al. 1975) or by excavation and washing. Final yield of grain and stalk was recorded and percentage reduction in grain yield over no compaction and moderate compaction was calculated.

RESULTS AND DISCUSSION:

i). Crop growth:- Crop growth responded very clearly to sub-surface compaction (Table 1). The significant differences in height of maize, pearl millet and mustard at three, four and eight weeks after sowing in presence of compact layer shows an adverse effect on early growth. The differences in maize and pearl millet were not significant at ten weeks after sowing, whereas significant differences existed at eleven weeks after sowing in mustard. This envisages that crops with tap root system are more susceptible to sub-surface compaction at shallow depth than cereal crops like maize and pearl millet with fibrous root system. Sangwan et al. (1974) conjectured that hard sub-soil horizons will do more harm to legumes compared to cereals having fibrous root system. Plant height at six weeks after sowing was reduced significantly in green gram and pigeon pea by a compact layer at shallow depth.

Table 1. Plant growth as affected by sub-surface compaction in crops.

Crop	No. of Weeks after sowing.	Plant height (cm)			C.D. at 5%
		Sub-surface compaction			
		No. compaction.	Moderate compaction	Severe compaction.	
Maize (1971)	4	35.8	31.4	27.7	4.15
	10	204.7	199.7	176.0	N.S.
Pearl millet (1972)	4	86.9	76.4	52.9	5.14
	10	191.3	176.4	158.7	N.S.
Mustard (1973)	6	37.0	29.0	21.0	2.4
	11	96.2	86.3	76.7	7.3
Green gram (1974)	6	48.0	42.0	40.0	5.8
Pigeon Pea (1974)	6	68.0	53.0	52.0	6.2

Depth of rooting appears to be a function of plant height (Ghildyal *et al.* 1974). Sangwan *et al.* (1974) and Agrawal *et al.* (1975) reported a considerable decrease in initial root penetration when a 5 cm thick hard pan of 1.6/1.7 and 1.8/1.9 g/cm^3 bulk density was present within 25 cm of root zone. With time, more roots penetrated through hard pan, particularly in cereals. Decrease in root penetration in presence of a hard pan was more in crops with tap root system than in cereals (Sangwan *et al.* 1974). Root penetration as measured by ^{32}P activity in plants (wheat, barley, chick pea and pea) on different days after germination is shown in table 2. Wheat and barley seem to be more tolerant to mechanical impedence in initial growth stages than pea and chick pea. A restricted root growth under sub-surface compaction, may limits the uptake of nutrients. Fried and Broeshart (1967), and Danielson (1972) reported reduced uptake of phosphate on poor structure soils restricting root growth.

Table 2. Effect of sub-surface compaction on root penetration of wheat, barley, pea and chick pea. (Gangwar *et al.* 1974).

Days after germination.	^{32}P counts/g/10 minutes			C.D. at 5%
	No compaction.	Sub-surface compaction		
		Moderate compaction.	Severe compaction.	
Wheat				
17	5933	784	476	521
45	7512	5251	4164	712
52	2685	2263	1641	19
73	766	453	407	10
Barley				
17	3142	619	411	511
45	7517	4652	3491	97
52	3793	2221	1519	95
73	814	415	268	12
Pea				
17	2018	212	119	292
45	4068	1425	909	64
52	2303	1712	1405	20
73	1186	944	422	32
Chick Pea				
17	2055	128	166	345
45	4066	1275	1126	182
52	3407	2179	1714	15
73	1064	730	551	7

(ii). Crop yield:- The grain and stalk yield of crops with tap root system significantly decreased with increase in sub-surface compaction (Table 3). This seems to be the result of early set back in growth which could not be recovered. The grain yield was not significantly affected by sub-surface compaction in cereals, although root growth and activity was reduced under sub-surface compaction. Taylor and [illegible] (1968) reported that crop yield may not be closely correlated with root growth.

Table 3. Grain and stalk yield of crops as affected by sub-surface compaction.

Crop		Yield (g/m2)			
		Sub-surface compaction			C.D. at 5%
		No compaction	Moderate compaction	Severe compaction	
Wheat (1970)	Grain	336	388	352	N.S.
	Stalk	488	388	344	N.S.
Maize (1971)	Grain	544	392	238	N.S.
	Stalk	2182	1747	1456	N.S.
Pearl millet (1972)	Grain	736	708	564	N.S.
	Stalk	2768	2266	1600	600
Mustard (1973)	Grain	147	94	60	22.2
	Stalk	580	438	328	119.0
Green gram (1974)	Grain	140	96	83	24.1
	Stalk	172	102	76	38.5
Pigeon Pea (1974)	Grain	64	39	17	11.7
	Stalk	573	401	250	80.5

The reduction in the grain yield of mustard, green gram and pigeon pea was of the order of 30-40 per cent at moderate level of sub-surface compaction, whereas in cereals either there was no yield reduction or upto 5 per cent at this sub-surface compaction (Table 4). Prihar **et al.** (1973) reported no adverse effect of dense layer at 22-26 cm depth on the yield of irrigated wheat.

Table 4. Yield reduction (%) at moderate and severe sub-surface compaction.

Crops	Reduction at moderate compaction over control.	Reduction at severe compaction over control.	Reduction at severe compaction over moderate compaction.
Wheat (1970)	+15.3	+4.7	+9.3
Maize (1971)	+14.0	30.9	39.3
Pearl millet (1972)	3.8	23.3	20.3
Mustard (1973)	36.1	59.2	36.2
Green gram (1974)	31.4	40.7	13.5
Pigeon Pea (1974)	39.1	73.4	56.5

+ indicates percentage increase.

At severe sub-surface compaction, the grain yield of crops reduced and the reductions were of the order of 40-70 per cent in crops with tap root system. The reduction in maize and pearl millet was of the order of 25 to 30 per cent at this sub-surface compaction. The greater yield reduction in crops with tap root system are attributed to the limited root zone or poor contact of roots with soil particles as the tap root growth practically ceases when encounters a high strength pan at shallow depth. Weight of mustard roots at flowering was 5.7, 2.2 and 1.7 g/plant at no compaction, moderate and severe compaction, respectively. The lateral growth of roots over hardpan was much more in cereals than in legumes (Agrawal et al. 1975; Sangwan et al. 1974) and this increased root proliferation appears to reduce the stress level at which the plant could obtained water supply and nutrients. Lowry et al. (1970) reported restricted water supply due to limited rooting volume under sub-surface compaction. The effect of sub-surface compaction on plant growth and yield particularly in cereals could be reduced by higher nutrient dressings and frequent irrigations, but crops with tap root system be avoided or deep tillage to break the hard pan be practised for greater yield.

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NO-TILLAGE PRODUCTION MANAGEMENT SYSTEMS FOR HILLY TERRAIN

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ABSTRACT

Field studies were conducted in the Appalachian mountain area to determine the feasibility of growing corn (*Zea mays* L.), a sorghum sudan hybrid (*Sorghum halepense* (L.) Pers.) variety Sudax, and other plant species in sods of several grass species. The objective was to develop management systems in which row crops can be grown in sod suppressed by herbicides to provide a continuous cover for water retention and reduced soil erosion. Silage yields of corn and sudax grown in suppressed sods of smooth bromegrass (*Bromus inermis* Leyss.), orchardgrass (*Dactylis glomerata* L.), and Ky-31 tall fescue (*Festuca arundinacea* Schreb.) was equal to or greater than yields with conventional tillage. Timothy (*Phleum pratense* L.) and bluegrass (*Poa pratensis* L.) were killed with low herbicide rates.

INTRODUCTION

Reduced or no-tillage corn production systems have been studied by several workers (1, 3, 4, 6, 7, 8). Most of these studies were conducted in previously killed sod or in corn stubble on Class I or II land. In hilly terrain, no-tillage systems can significantly reduce runoff and erosion until the killed grass mulch is lost, but then the area must be reseeded to prevent major soil erosion (2, 3, 5). Therefore, a no-tillage system with a suppressed, rather than a killed, sod would be highly desirable. In developing such a management system, the choice of sod species is a predominant factor. For hilly terrain grass species that have a wide herbicide tolerance range and can remain semidormant for long periods and then rapidly recover are highly desirable (2, 3).

EXPERIMENTAL PROCEDURE

Field studies were conducted from 1966 to 1968 in West Virginia on a Ultic Hapludalfs, fine-loamy, mixed, mesic soil to determine the effect of two rates of atrazine (1.7 and 3.5 kg/ha) with 0.56 kg/ha of paraquat on silage yields of corn no-till planted in smooth bromegrass (*Bromus inermis* Leyss), orchardgrass (*Dactylis glomerata* L.), timothy (*Phleum pratense* L.), Ky-31 tall fescue (*Festuca arundinacea* Schreb), or Kentucky bluegrass (*Poa pratensis* L.). A split plot experimental design was used in which sod species and tillage systems were main plots and atrazine rates were subplots. Each plot had five replications. Hay was harvested annually in May and plots were fertilized uniformly with a broadcast application of 112, 49, and 142 kg/ha of N, P, and K. New Jersey-8 variety field corn was planted on June 6, 1966, and June 10, 1967, with a specially designed sod planter. Atrazine and paraquat were applied immediately after planting.

A second study was conducted in 1968 and 1969 near Morgantown, West Virginia to determine the effect on silage yield of removing the hay vs. leaving it as a mulch. New Jersey-8 variety of field corn was no-till planted in June at 50,000 plants/ha in Ky-31 tall fescue and orchardgrass sod on an Aquic Hapludult, clayey, mixed, mesic soil with a 15% slope. Treatments included two rates of atrazine (2.24 and 4.48 kg/ha) in combinations with two rates of paraquat (0.28 and 0.56 kg/ha) on each sod species both with and without hay removed. A split-plot design with four replications was used with sod species as main plots, cutting treatments of forage as subplots, and herbicide rates as sub-subplots. All plots were fertilized uniformly with a broadcast application of 168, 49, and 93 kg/ha of N, P, and K. Corn was harvested for silage when in the late dough stage.

A third study was conducted in 1970-72 on an Aquic Fragiudults, fine-loamy, mixed, mesic soil with a 10% slope to determine effect of atrazine rates on bromegrass hay yields and silage yields of corn no-till planted in bromegrass sod. Atrazine was applied at 1.68, 2.24, 2.80, 3.36, 3.92, and 4.48 kg/ha with 0.56 kg/ha of paraquat. A crop of hay was removed annually and the area fertilized with 224, 73, and 129 kg/ha of N, P, and K. Plots were then sprayed with appropriate herbicide rates and planted to SS-866 variety of field corn. A randomized complete block experimental design with four replications was used.

A fourth study was conducted in 1969 and 1970 to determine the potential of interseeding Sudax (Sorghum halapense (L.) Pers.) a sorghum-sudan hybrid, into stands of Ky-31 tall fescue, orchardgrass, or timothy without killing the grasses. Paraquat was used at 0, 0.28, and 0.56 kg/ha in a randomized complete block design with four replications. Sudax was planted in 36-cm rows at the rate of 28 kg/ha on August 15, 1969, and June 17, 1970, using a sod planter. One harvest was made in 1969 and two in 1970. Yield determinations are based on plant samples oven dried at 65 C. Plots were fertilized each year with 118, 34, and 65 kg/ha of N, P, and K.

RESULTS AND DISCUSSION

In 1966 and 1967, uniform populations of corn were obtained in all sod species. Corn grew faster in bromegrass sod than in sod or other grass species both years; however, corn grew faster in sod of all five grass species than when grown under conventional tillage. In 1966, the faster growth of corn in bromegrass sod continued until early tasseling, at which time the plants showed N deficiency. Bromegrass regrowth was heavy, especially at the low rates of atrazine, and N supply was insufficient for optimum growth of both corn and bromegrass. An additional 90 kg/ha of N was applied to all plots, but corn yields in bromegrass plots was irreversibly reduced. In 1966, corn silage yields from no-tillage plots were highest in tall fescue sod with the 3.4-kg/ha atrazine rate and lowest in bluegrass sod at the 1.7-kg/ha atrazine rate (Table 1). The lowest yield (27.1 t/ha) was from the conventional tillage treatment with 3.4 kg/ha atrazine. Much of the yield difference in sod-planted corn could be associated with the substantial regrowth of bromegrass, orchardgrass, and tall fescue at the lower atrazine rate.

Significant yield differences were again associated with sod species and atrazine rates in 1967. The highest yield (72.7 t/ha), produced in bromegrass sod with 3.4 kg/ha of atrazine, was more than double the yield from conventional tillage plots at the same atrazine rate. Corn silage yields in bromegrass, timothy, orchardgrass, and fescue sods were higher with the higher rate of atrazine; however, silage yields in Kentucky bluegrass sod were lowest at the higher rate of atrazine. Silage yield differences were again associated with rates of atrazine and sod regrowth of bromegrass, orchardgrass, and tall fescue. At the low atrazine rate, orchardgrass crowded out the corn, resulting in no silage yield. However, corn silage yields were good in orchardgrass at the higher atrazine rate.

The major objective of this study was to determine if sod-planted corn can be grown in a double-cropping system with hay removed in the spring and followed by a corn crop. All plots were harvested for hay

Table 1. Effect of rates of atrazine on silage yields of corn sod planted in five grass species, and on hay yields in the spring following corn harvest, Point Pleasant, West Virginia.

Sod Species	Silage yields-35% DM 1966 Atrazine-kg/ha 1.7	3.4	1967 Atrazine-kg/ha 1.7	3.4	Hay yields-DM 1967 Atrazine-kg/ha 1.7	3.4	1968 Atrazine-kg/ha 1.7	3.4
	t/ha							
Bromegrass	33.2	35.3	65.6	78.7	4.0	3.2	4.9	2.4
Timothy	41.7	39.9	59.2	63.2	0	0	1.8	0
Bluegrass	31.8	40.4	54.7	46.2	0	0	0.1	0
Orchard-grass	32.3	38.8	0	46.2	2.9	0.7	4.4	0.9
Fescue	42.6	46.4	18.4	66.4	3.1	2.2	4.1	1.3
Plowed	28.8	27.1	46.0	30.7				
LSD 0.05	4.95		7.11		0.94		0.97	

yields each year immediately before corn was planted. Hay yields in 1966 before herbicide applications ranged from about 2.4 to almost 4.0 t/ha depending on the species. Hay yields in the spring of 1967 varied widely among species due to atrazine rate (Table 1). Atrazine killed timothy and bluegrass. Bromegrass, orchardgrass, and Ky-31 tall fescue made good recovery after the first corn crop. Hay yields were highest at the low atrazine rate, with bromegrass producing the highest hay yields of any species at both atrazine rates. The small timothy and bluegrass yields in 1968 at the low atrazine rate were due to natural reseeding, not from sod recovery. After 2 years of double cropping for no-till corn and hay production, grass stands were excellent (nearly 100%) for bromegrass, orchardgrass, and tall fescue at the low atrazine rate and averaged approximately 85% for bromegrass and tall fescue at the high atrazine rate.

Silage yields from corn sod planted in orchardgrass and tall fescue as affected by rates of atrazine and paraquat and removal of hay are given in Table 2. Average hay yields before planting corn in 1968 were approximately 4.7 and 6.5 t/ha for orchardgrass and tall fescue, respectively. In 1968, corn silage yields were highest (38.6 t/ha) when planted in uncut orchardgrass sod at the higher rates of atrazine and paraquat. Corn silage yields in orchardgrass sod were higher for most treatments in the uncut grass than where hay was removed, except where the lower rates of atrazine and paraquat were used. Conversely, silage yields in tall fescue sod were always greater when hay was removed. When tall fescue hay was removed, corn silage yields did not differ among atrazine or paraquat rates. When tall fescue hay was not removed, yields were significantly increased by using the higher atrazine rates and by the higher paraquat rate applied with the lower atrazine rate. Evidently, the heavy grass growth harbored injurious insects, shaded the early corn plant growth, and caused some competition for soil moisture and nutrients.

In 1969, corn silage yields were highest in the uncut plots of both orchardgrass and fescue when 2.24 kg/ha of atrazine plus 0.56 kg/ha of paraquat were applied. The high rate of paraquat increased yield of corn in orchardgrass sod whether the hay was removed or left uncut. Since paraquat is a contact herbicide, this increased silage yield probably represents a faster kill of the orchardgrass with resultant less competition for available soil moisture. Corn grown in tall fescue sod also produced higher yields when treated with 0.56 kg/ha of paraquat except on the uncut plots at the high rate of atrazine.

Grass recovery was considerably less at the higher vs. the

Table 2. Effect of atrazine and paraquat applied on two sod species, with and without hay removal on silage yields of sod planted corn.

Treatment Herbicide rates		Corn Silage Yields (35% Dry Matter) 1968				1969			
		Orchardgrass		Ky-31 Tall Fescue		Orchardgrass		Ky-31 Tall Fescue	
Atra-zine	Para-quat	Hay Removed	Grass un-cut	Hay Removed	Grass un-cut	Hay Removed	Grass un-cut	Hay Removed	Grass un-cut
kg/ha	kg/ha	t/ha							
2.24	.28	32.2	21.8	29.0	17.0	38.2	31.8	61.1	55.7
4.48	.28	28.5	35.7	30.1	22.8	34.4	41.2	53.8	50.2
2.24	.56	32.2	33.7	30.4	19.2	49.6	55.2	66.6	72.8
4.48	.56	34.0	38.6	31.4	22.1	48.3	49.7	62.7	60.9
Average		31.73	32.45	30.22	20.13	44.89	44.48	60.63	60.4
Conven. Tillage 17.19									

Statistical analysis probability levels at which F ratios are significant: Between sod species - .01 (1968) and .001 (1969); Hay removed or uncut - .05 (1968) and N.S. (1969); Between rates of paraquat - N.S.

lower atrazine rate. However, sufficient grass was present to provide a good mulch at both atrazine rates. The higher paraquat rate was more important when the grass was left uncut than when harvested for hay. This would be expected since additional paraquat was needed to quick-kill the large quantity of plant growth present and thus avoid appreciable soil water loss by transpiration. In general, silage yields from corn sod planted in both grass species were higher than yields from conventional tillage in 1968, but only from tall fescue in 1969. The merits of leaving a large amount of plant material as a mulch rather than removing it as a hay crop is questionable. Apparently, sufficient mulch is left when the grass is cut for hay to provide adequate soil protection and reduce evaporation.

Additional studies were conducted in 1970-1972 to determine the most desirable rate of atrazine for use on bromegrass in a continuous hay-no-tillage corn production system. The effect of rates of atrazine on hay and corn silage yields are shown in Table 3. Corn

Table 3. Effect of rates of atrazine on corn silage yields sod planted in bromegrass and bromegrass hay yields, Morgantown, W. Va.

Treatment*	1970	1971		1972	
Atrazine	Silage	Hay	Silage	Hay	Silage
kg/ha	t/ha				
1.68	22.09e**	4.03a	31.05c	3.54bc	44.54a
2.24	33.65d	3.54ab	31.17c	4.48ab	38.33c
2.80	57.08b	3.04bc	30.34c	4.01bc	44.58a
3.36	48.67c	3.29ab	32.67c	5.15a	39.75c
3.92	55.96b	2.70bc	41.38a	3.11cd	42.82bc
4.48	64.66a	2.10c	39.33b	2.86d	43.70ab

* In addition all plots were sprayed with 0.56 kg/ha of paraquat.
** Values followed by same letter for treatments within same year are not significantly different according to Duncan's multiple range test.

silage yields generally increased with increasing rates of atrazine in 1970 with the exception of the 3.36-kg/ha rate. Yields ranged from 22.1 to 64.7 t/ha and were generally in proportion to the regrowth of bromegrass sod. Hay yields in 1971 ranged from 2 to 4 t/ha and decreased with increasing atrazine rates. Even at the highest atrazine rate (4.48 kg/ha) bromegrass had appreciable regrowth. The 1971 corn silage yields were nearly equal for the 1.68- through the 3.36-kg/ha atrazine rates. Only the 3.92 and 4.48 kg/ha atrazine rates produced higher yields. In 1972, corn silage yields were reduced by wind damage. In 1972 the hay yields taken before planting corn show an increase for the 1.68- to the 3.36-kg/ha atrazine rates. One would normally expect a reduction in bromegrass regrowth after 2 years of atrazine applications, but increased hay yields were obtained at all but the highest atrazine rate. Silage yields of corn in 1972 did not differ significantly between the lowest and highest rate of atrazine. Bromegrass stand was excellent on all plots after corn harvest, indicating that a double-cropping system using bromegrass for both hay and corn is feasible. At all locations, live bromegrass actually stimulated the corn growth.

Yields of Sudax planted into sods of three grass species as affected by paraquat treatments are shown in Table 4. In 1969, yields were small because sudax was not planted until mid-August. However, sufficient information was obtained to indicate the feasibility of this production technique. Good stands of sudax were obtained in all grass species, even when no paraquat was used to suppress the sod. Sudax yields in fescue sod were highest without paraquat application. Sudax in orchardgrass sod produced the highest yield when 0.28 kg/ha of paraquat was applied. Yield of Sudax grown in timothy sod increased with increasing rates of paraquat.

The two harvests of sudax made in 1970 had comparable yields. Rates of paraquat had little or no effect on total yields of sudax planted in any of the three sod species. These data indicate that good yields of sudax interseeded into existing sod, can be obtained providing that the sudax is planted soon after grass is harvested to avoid appreciable grass regrowth. Good regrowth of the three sod species were obtained after sudax was harvested.

Other studies have been conducted in West Virginia on the no-tillage technique for production of potatoes and tomatoes. In general, both of these species have yielded significantly higher when the no-tillage production technique was used as compared with conventional tillage. More than 64 t/ha of marketable tomatoes were produced where tomatoes were no-till planted in rye sod. Potato yields, when no-till planted in rye sod, averaged more than 33 t/ha over a 3-year period.

Table 4. Hay yields of Sudax interseeded in three sod species sprayed with three rates of paraquat, Morgantown, West Virginia.

Sod Species	Paraquat	Sudax hay yields 1969*	1970 First Cutting	1970 Second Cutting	Total Harvest
	kg/ha	t/ha			
Fescue	0.00	1.5	5.3	4.6	9.9
	0.28	1.3	4.8	5.9	10.7
	0.56	1.5	5.0	6.2	11.2
Orchardgrass	0.00	1.0	4.8	4.0	8.8
	0.28	1.9	5.0	4.2	9.2
	0.56	1.7	5.0	4.2	9.2
Timothy	0.00	0.9	5.4	5.1	10.5
	0.28	2.2	5.4	4.0	9.4
	0.56	3.1	5.0	6.0	11.0
LSD		0.62	N.S.	N.S.	N.S.

*Planted in August

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Notes on soil structure homogeneity and rootability.

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ABSTRACT.
After a discussion of homogeneity of soil structure with respect to mean pore space, pore size and oxygen diffusion rate, a soil rootability index is defined and an example of a rootability experiment is discussed.

1. VARIABILITY OF TOTAL PORE SPACE.

Soil structure is the mutual arrangement and binding of the solid particles. Soil structure homogeneity can be defined as the inverse of the smallest volume that represents correctly the whole (Kuipers a.o. 1966). Samples smaller than this representative volume will show an increasing variability with a decreasing sample volume. In table 1 samples of 80, 40 and 20 cc from a tilled and untilled heavy marine silt soil are compared.

table 1	p.v. (v/v) \ volume (cc)	standard deviation 80	40	20
ploughed	45,7	3,21	3,55	3,74
untilled	38,4	1,49	1,55	1,67

Variability of pore space of the tilled soil is clearly higher than of the more compact untilled soil. With both soils there is only a minor influence of sample size on variability. This indicates that sample size is not very critical in this range. Whereas 20 cc is already a rather unpractical small size for routine determination, samples of at least 100 cc are preferred for homogeneity determinations based on total pore space.

On a tilled and a four years untilled fine textured river levee soil pore space and root dry weight in 100 cc samples taken at the same distance from plant rows (peas at flowering) were determined (table 2).

table 2	depth (cm)	p.v. (v/v) $\bar{x}$	root dry weight (mgr) $\bar{y}$	$y = ax + b$	s_a	corr. coeff. r
ploughed	2-7	59,1	28,8	$y = 0,2x + 20,7$	0,72	0,05
	12-17	50,9	17,5	$y = 1,2x - 41,2$	0,54	0,33
	22-27	50,9	11,5	$y = 0,4x - 10,7$	0,47	0,15
untilled	2-7	48,2	35,4	$y = 1,4x - 31,0$	1,22	0,18
	12-17	47,3	13,0	$y = 2,3x - 93,8$	0,64	0,50
	22-27	47,8	9,0	$y = 1,2x - 50,1$	0,88	0,22

In the second half of the arable layer there is a significant positive relation between root weight and pore space. Even in these cases variability in root weight is explained only to a small extend by pore space.

2. VARIABILITY OF PORE SIZE DISTRIBUTION.

Larger pores are likely to be more susceptible to compaction than smaller pores. Nevertheless even in very compact soils rather large pores may be present, be it in a small number (Boone a.o. 1976 (1)). A procedure has been developed for measuring directly the number and spatial distribution of different pore size classes on large series of soil samples. Air dry undisturbed soil samples are polished very gently, using abrasive paper. Loose solid particles that may cover pores are removed by air suction and a photograph is taken. With a scanner (Quantimet 720) quantitative measurements can be made very fast (Jongerius 1973). Pores down to about 90 µm are measured quite satisfactorily. It may be necessary to exclude parts with shrinkage cracks from measurement. On a heavy marine silt soil a 5 years untilled plot and a ploughed plot were compared. The relation between amount of pores over a certain size and pore space in the sample can be determined for both structures. It appears that these relations are clearly different for these two structures (fig 1).

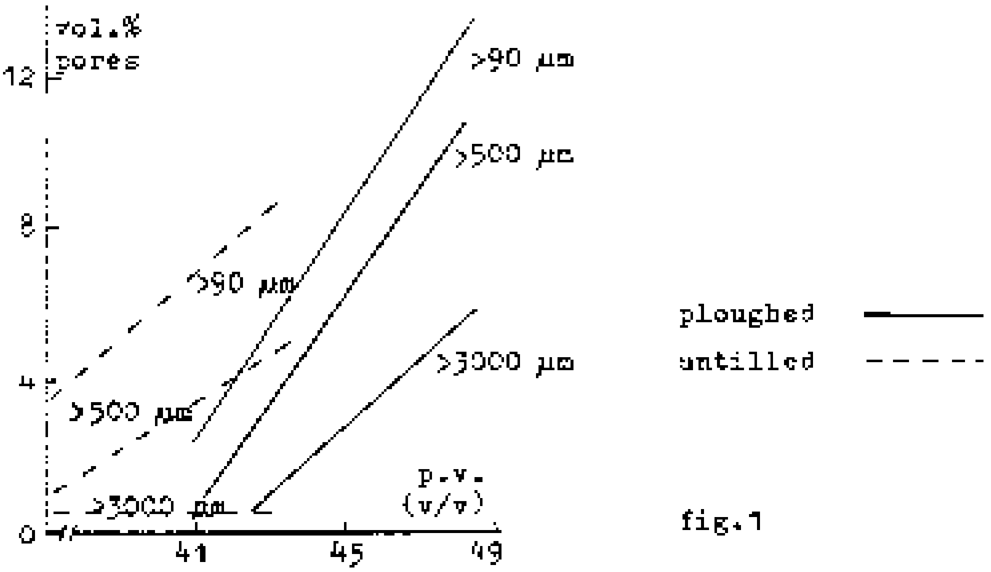


fig.1

On the ploughed soil nearly half the volume of pores >90 µm are pores >3000 µm. On the untilled soil this is far less. At the same total pore space the untilled soil is containing a higher volume of pores between 90 and 3000 µm and especially in the range 90 - 500 µm.

The standard deviation of volume of different pore size classes is higher the larger the pores are. In the ploughed soil standard deviation of pore volume for pores >3000 µm is 130% (±10,4), for pores >500 µm 61% (±6,3) and for pores >90 µm 43% (±4,4). The number, spatial distribution and continuity of the large pores are very important in relation to the soil physical growth factors as well as rootability. It appears that if soil structure is to be characterized by large pores, homogeneity is likely to be less than if total pore space is regarded.

3. HOMOGENEITY OF AERATION CHARACTERISTICS.

Aeration of a wet soil depends to a large extend on continuity of the system of large pores. Mean aeration of total soil mass of an untilled soil is generally lower than of a tilled soil. This appeared very clearly on a heavy river levee soil where active gley was observed in the arable layer of the untilled soil (Boone a.o. 1976 (1)). Nevertheless rootgrowth needs not to be

really hampered as long as sufficient places with an adequate aeration excist. Root volume will never be more than a few percent of the volume of the tilled layer even with very luxurious rootgrowth. Oxygen concentration in the gasphase depends on the equilibrium between supply and removal of oxygen. Both change continuously, supply by changes in water content and consumption by extension of the root system and by changes in microbial activity. Moreover all these aspects depend largely on depth and even at constant depth there are large local differences.
In soil tillage experiments it turned out that variability in oxygen content is greater the lower the mean oxygen concentration is. Low mean oxygen concentrations, with a high standard deviation were observed especially below rooting depth in the first stages of crop growth. Variations in oxygen concentration therefore are primarily related to the oxygen supply. Lowering soil water tension is accompanied by local steep decreases in gasdiffusion. These spots are characterized by a relatively low number of continuous pores filled with air at that particular soil water tension. The interconnected parts of the soil with a relatively high number of large pores will contain most roots. So it seems likely that the number of spots with a good aeration is a better criteria for rootability than the mean aeration status.
The oxygen diffusion rate (O.D.R.) emphasizes the oxygen diffusion in the thin saturated soil layer around the root. The root is simulated by a platinum wire with a length of about 1 cm, so local conditions are very important for the results. In a very dense soil water content by weight at field capacity is lower

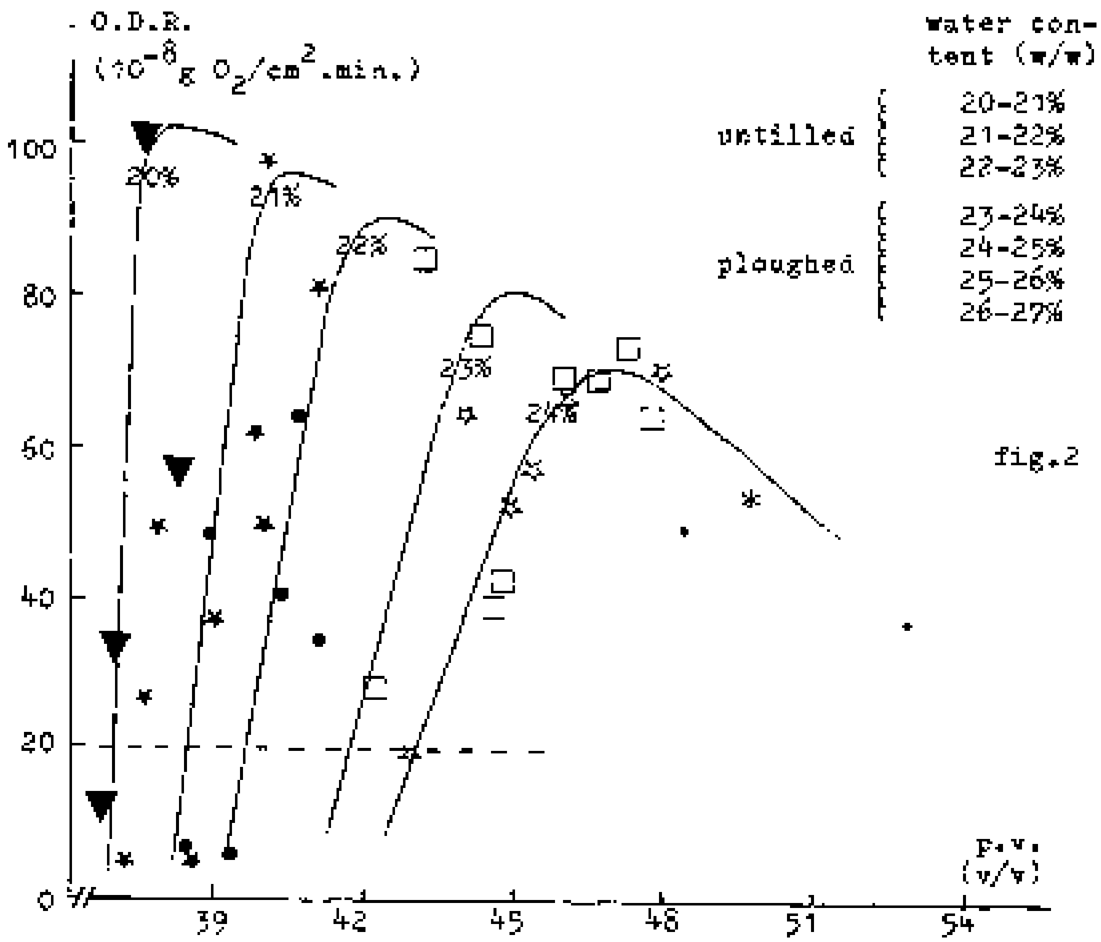


fig.2

than in a loose soil (Kuipers 1961). This is the mean reason that O.D.R. at field capacity in an untilled soil is almost as high as in the ploughed soil. At the same time variability in O.D.R. is higher with lower total pore space (fig.2; heavy marine silt soil at pF 2,0).
Especially in a very dense soil small variations in pore volume and/or water content have an enormous impact on O.D.R. Variability of O.D.R. inside undisturbed core samples is even higher than between samples. The percentage of spots with a insufficient aeration (O.D.R. <20 x 10^{-8}g O_2/cm^2.min) is higher in a untilled soil and this holds also for lower sections (table 3).

Table 3	p.v. (v/v)	O.D.R. (10^{-8}g O_2/cm^2.min.) pF2,0		pF1,7		pF1,5	
		$\bar{y}$	%<20	$\bar{y}$	%<20	$\bar{y}$	%<20
ploughed	46,0	57,4	16	56,5	39	17,4	67
untilled	39,1	40,1	43	27,1	55	12,4	82

It can be concluded that homogeneity with respect to aeration is not likely to be related in a simple way to homgeneity of pore space distribution, because of the sharp reactions observed by minor changes in pore space and moisture content especially in a dense soil.

4. SOIL STRUCTURE AS A RISK FACTOR.

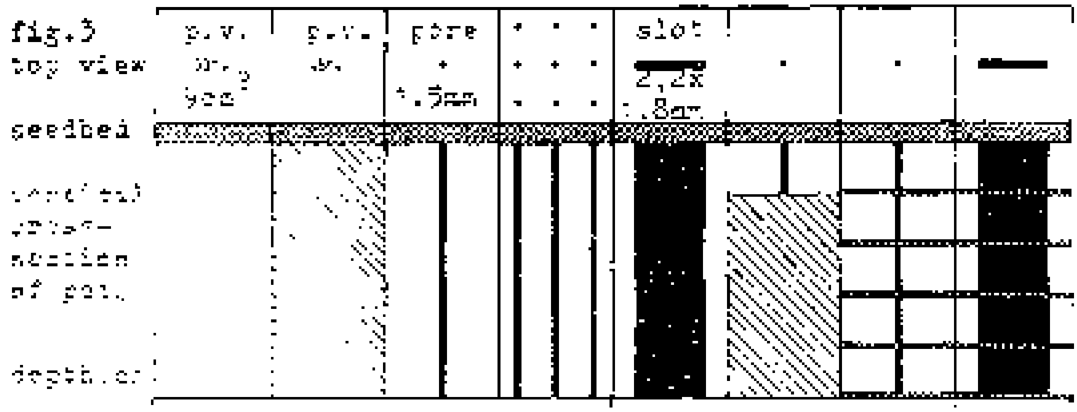
Soil environment influences the length and proliferation of a root system, not the diameter of single roots. Root diameter of even fine rooted crops exceeds 100 µm. Soil exploration is initiated by roots of a lower order (e.g. main roots), proliferation mainly by roots of higher order. Relatively thick roots are important in the first stages of rootgrowth and also with respect to ultimate effective rooting depth.
In a homogeneous soil with pores smaller than roots (made by drying a puddled soil to pF 2,0) reasonable rootgrowth could only be obtained if the water content was kept rigidly constant. It was observed that on this occasion rootgrowth rate of flax at pF 2,0 was about half of the rate obtained in the control, with a favourable structure. In general, the better soil structure is, the less critical water content will be. Therefore soil structure should be judged in dependance of soil water conditions to be expected (Boone 1976 (2)).
Crop reactions can be expected when there is an unbalance between crop demands and availability of water, ions and oxygen to plant roots. A smaller root system increases the probability of crop reactions, especially under marginal conditions. Therefore early stages of crop growth are more likely to be influenced (Finney and Knight 1973). For different crops early growth may be important for different reasons. Spring barley e.g. has a short growing season and for sugar beet date of crop closure is important. In general root growth retardation leads to a lower ultimate rooting depth and/or lower root density. Two remarks should be made. Root density is sometimes higher than normal below a layer with restricted rooting (compensation). In the second place rootability of soil below the arable layer may be low for various reasons even if visually soil structure seems quite adequate.
Heterogeneity of even very dense soil structures in the field is higher than in model research with compacted aggregates. This complicates interpretation of functional relationships between soil

physical factors and root growth. It may also offer new perspectives if a physical description of the soil and an empirical rootability determination are combined. A rootability index can be defined as the relative root growth rate of undisturbed samples compared with a standard soil structure of the same soil with a known very high rootability. The rootability can easily be tested when a very high number of roots is offered to a test structure during a certain time under standard environmental conditions. Tests at different soil water regimes will give information on maximum root growth rate as well as on root growth flexibility. Soil structures with a higher flexibility are regarded to be favourable. A safe lower limit of soil structure can be found by comparing the number, area and distribution of the spots that have a high rootability even under extreme conditions with root density considered necessary at that time and depth in the soil profile. For less favourable soil structures risks involved may be evaluated by such comparisons.

5. PORE AND ROOT GEOMETRY.

On a good structure there are more roots than really needed. Simulation (van Keulen a.o. 1975) suggests that root density of active roots need not to be high. Root pattern and density can be changed by modifying artificially the number, dimension and distribution of the large pores in a very dense soil (fig.3; pore space 35%; root density (cm/cm^3) after four weeks (flax)).

fig.3



depth cm								
2-7	4,6	9,9	6,[illegible]	6,[illegible]	5,9	6,6	5,5 33,4*	4,2 26,4*
7-12	1,1	6,7	2,6	2,0	2,2	5,[illegible]	1,6 25,6*	5,3 23,[illegible]*
12-17	0	4,[illegible]	[illegible]	1,5	[illegible],3	2,5	0,5 8,4*	2,2 16,0*
17-22	0	4,[illegible]	0,[illegible]	0,9	[illegible]	2,2	0,7 0,3*	1,0 [illegible]*
22-27	0	5,9	0,3	1,7	[illegible],2	[illegible]	0,0 0,[illegible]*	0,- 5,8*
fresh weight (g) sprout	4,7	16,3	6,3	8,[illegible]	[illegible],2	12,2	9,4	[illegible]

*) thin loose layer

Even with a rigid controlled water system roots grew in a soil with a pore volume of 35%. Nevertheless striking differences were found in root- and sproutgrowth when artificial channels were introduced. In order to reach the same root- and sproutgrowth quite a number of artificial pores are needed. In this respect slots are already better adapted to the root system than single vertical channels. Abrupt variations in soil structure decrease root extension very much. Compensational root proliferation takes place in the spots with a high rootability. Later on when available pot volume is a limiting factor the differences decrease but do not disappear even not in sproutgrowth.

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COMPARATIVE STUDIES OF DIFFERENT WAYS OF SEEDBED PREPARATION FOR MAIZE (Zea mays L.) IN COMBINATION WITH MINERAL FERTILIZERS

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ABSTRACT

The three-year comparative studies of different ways of seedbed preparation for maize in combination with mineral fertilizers, in the conditions of the semi-humid climate in the continental part of Croatia, on lessivé brown soil on sandy substrata, did not show any expressed gain for maize yield in any of the studied ways of seedbed preparation, either by the aggregate roller-cultivator-roller or disc-harrow or combined implement. Even direct sowing into the furrow appeared equally acceptable. Fertilizing had a significant effect and was dominant in relation to different ways of seedbed preparation.

The practices applied in the trial brought about positive changes of some chemical and to a smaller extent physical properties of the soil, but they were not significant.

INTRODUCTION

Recently, new trends have appeared in soil tillage, aiming at a reduction of the costs and labour in the tillage itself and also in other practices in crop growing, provided the same or higher yields are obtained. Thus, the main objective is the rationalization of the production process, depending on ecological conditions and crop requirements, the latter being the decisive factor for the scope of rationalization.

Rationalization or minimization of soil tillage, in general, and also for maize, up to its complete omission, has been the subject of a number of recent works (Blake and Aldrich, 1955; Musgrave, 1955 and 1956; Free, 1960; Mayer and Mannering, 1961; Free et al., 1963; Singh et al., 1966; Triplett, 1966; Griffith et al.; Jones et al., 1968; Ivanov et al., 1971; Sziposz, 1972; Bakermans and de Wit, 1973; Van Doren and Triplett, 1973; Milojić, 1973; Kaposzta, 1973 and others).

There are many factors which have to be considered when reducing tilling practices, so that various ways of seedbed preparation for maize, especially if the compensating effect of fertilizing is taken into account, offer possibilities of reducing the number of operations, particularly on soils with favourable physical properties, primarily well drained. Our investigations should be taken as an attempt to assess, as objectively as possible, which system of tillage is optimal in given conditions. Thus, in case of minimum tillage, it is hard to believe that this system could be acceptable in our conditions in its totality, but there is no doubt, that it is not only possible but also necessary to reduce tilling operations without adversely effecting the yield. This was taken as the starting point for our investigations, at the first stage of which there was only a certain reduction of the tilling operations in the seedbed preparation for maize, with complete omission of cultivation in the course of the growing period. These preliminary studies were followed by more extensive investigations, including also the no-tillage system.

INVESTIGATION METHODS

The trial was stationary, lasted for three years, and was carried out according to the modified split-block scheme in four replications. Four seedbed preparation variants were studied in combination with four fertilizer doses for maize, hybrid Bc-SK5A. The basic tillage, together with basic fertilizing with phosphorus and potassium fertilizers, and partly nitrogen fertilizers, was carried out in autumn, at the average depth of 25 cm. The following ways of seedbed preparation were investigated:

1. Soil preparation by the aggregate roller-cultivator-roller (I); 2. Soil preparation by disc-harrow (II); 3. Sowing directly into furrow (III); and 4. Soil preparation by combined implement (spring tooth harrow - bar roller)(IV).

The seedbed preparation was preceded by pre-sowing nitrogen fertilizing, which was accompanied by starter fertilizing with complex fertilizers, sowing and herbicide application.

The fertilizer doses, adjusted to the nutrient content in the soil, crop requirements and investigation character, were, besides check, the following: low - N_{120} P_{100} K_{100}; medium - N_{160} P_{140} K_{160} and high - N_{200} P_{180} K_{200}.

INVESTIGATION RESULTS

A) Yield

When analysing the effects of the investigated factors, that is tillage, fertilizing and their combinations, it should be firstly stressed that fertilizing was highly significant in all three experimental years (Table 1). The seedbed preparation was significant only in the first year.

If further analysis is made of the obtained results effected by the tillage itself, not taking into account the borderline differences, the seedbed preparation with combined implement was the best in two of the three experimental years. However, it should be mentioned that in the second year, direct sowing was the best, which also in the third year approached the best treatment. In the first year, all the other three treatments were significantly better than direct sowing into the furrow. On the other hand, the tillage with combined implement was significantly better than that with disc-harrow. In the second and third years, the tillage, as already mentioned, was not significant, which is confirmed by the borderline values, which are given contrary to the usual practice. Thus, if there seems to be an advantage of any of the studied treatments, it is, accordingly, relative.

On the other hand, under the influence of fertilizing there is a steady increase in the yield parallel to increasing

Table 1 – Grain yield of maize, q/ha and some chemical and physical properties of soil

Treatment		Yield 1971.	Yield 1972.	Yield 1973.	P_2O_5 mg/100 g soil 1971.	P_2O_5 mg/100 g soil 1973.	[illegible] 1971.	[illegible] 1973.	Base saturation, % 1971	Base saturation, % 1973.	[illegible] 1971.	[illegible] 1972.	[illegible] 1973.
Seedbed preparation													
I		151,7	72,0	60,8	9,8	11,0	9,8	13,5	53,8	54,3	44,5	20,6	23,8
II		129,8	77,4	53,4	9,1	12,3	9,2	14,1	54,7	55,8	44,1	24,7	23,5
III		119,5	79,8	56,6	9,4	11,9	9,4	13,5	53,5	55,4	44,5	24,7	[illegible]
IV		137,9	76,2	58,7	9,2	12,3	9,2	14,4	53,3	55,1	39,5	21,9	[illegible]
LSD	P=5%	7,7	6,9	8,7	1,6	2,7	2,1	2,8	4,3	1,3	7,8	4,5	[illegible]
	P=1%	11,1	9,5	10,5	[illegible]	3,8	3,0	4,0	6,1	1,8	11,7	6,4	[illegible]
Fertilizing													
I		111,5	59,0	39,7	8,5	10,1	8,4	14,3	35,4	57,1	41,7	25,7	20,8
II		129,4	79,7	90,2	9,3	10,9	9,3	13,5	35,9	54,5	40,5	21,4	[illegible]
III		137,6	80,5	101,8	9,5	13,2	9,5	15,5	35,3	52,0	49,0	27,4	[illegible]
IV		140,3	86,2	107,8	10,2	13,5	10,4	12,7	35,7	55,6	44,1	21,4	22,2
LSD	P=5%	6,8	10,0	12,2	1,3	4,9	1,3	2,4	4,3	2,5	5,8	4,6	[illegible]
	P=1%	10,2	15,2	18,6	2,0	5,9	2,0	4,7	6,5	3,8	8,8	6,7	[illegible]
Seedbed preparation x fertilizing													
I	Check	111,3	52,0	36,9	8,1	9,9	8,1	12,0	55,8	57,3	41,5	25,0	[illegible]
II		109,3	57,7	40,4	9,0	9,4	9,0	12,4	54,2	57,0	46,5	25,0	19,5
III		104,0	57,8	42,4	9,0	10,0	9,0	14,2	57,8	57,4	44,8	24,7	22,7
IV		121,1	55,3	33,1	7,8	11,0	7,6	13,2	52,5	56,8	32,7	26,0	19,5
I	Low	130,9	74,7	65,5	10,0	11,2	10,0	13,4	52,0	54,5	46,9	21,6	[illegible]
II		132,0	78,8	65,8	9,1	10,4	9,1	13,4	58,1	54,2	40,0	24,7	[illegible]
III		119,2	64,8	93,8	8,1	11,2	9,1	12,1	59,1	54,9	37,2	24,7	[illegible]
IV		136,2	80,0	95,6	10,0	10,9	10,0	12,3	54,6	53,8	37,6	21,8	[illegible]
I	Medium	145,8	79,7	99,6	11,1	11,0	[illegible]	14,0	52,4	51,4	53,4	18,2	[illegible]
II		136,7	85,3	100,7	8,4	13,6	8,4	15,5	51,0	54,4	42,7	25,0	[illegible]
III		124,7	78,3	93,1	10,0	13,5	10,0	12,5	47,2	52,4	51,6	25,4	25,0
IV		143,3	73,0	107,8	6,5	14,5	6,5	15,4	51,9	54,7	38,4	22,1	15,4
I	High	138,4	81,8	100,7	9,9	11,5	9,9	11,5	57,0	53,9	42,1	24,4	20,6
II		140,9	87,7	106,9	10,4	15,9	10,4	13,1	55,4	56,8	50,2	22,1	23,6
III		151,1	87,2	110,9	10,6	12,5	10,5	12,6	56,6	57,0	45,4	23,1	19,5
IV		150,7	88,2	112,2	10,6	13,0	10,6	13,5	53,8	53,0	36,5	18,2	24,9
LSD	P=5%	24,3	15,0	15,0	3,4	3,2	2,9	4,6	13,4	7,1	17,7	8,1	[illegible]
	P=1%	32,5	20,0	20,1	4,8	4,5	4,0	6,4	18,4	9,8	24,3	11,2	[illegible]

fertilizer doses, particularly when changing from unfertilized to fertilized variants. If the yields are analysed per years, this increase is significant in the first year between the unifertilized treatment and the other three fertilizer rates. There is a significant yield increase of the medium and high in relation to the low fertilizer doses. In the second year, there is also a very significant difference between the unfertilized and fertilized treatments. There are no significant differences between fertilized treatments. In the third year, a highly significant difference appears between the unfertilized and fertilized treatments, while within the fertilized treatments there is a significant difference only between the low and high fertilizer doses.

The total yields per years give a certain insight into the common effect of the tillage and fertilizing treatments. A certain, though not the expected, degree of interaction is noticable. The best combination of the trial was that of the seedbed preparation with combined implement and high fertilizer dose. As a rule, the highest significance is recorded between the fertilized and unfertilized combinations, higher at higher fertilizer doses. With the further increases of fertilizer doses, the significant differences between them are either poorly expressed or non-existent. The differences in yield, irrespective of treatments, in particular years are relatively high, especially between the first and the other two years. They can be explained by hydrothermal relations, and also by the fact that the growing of maize in the trial was preceded by the annual growing of maize, which was preceded by perennial growing of lucerne.

B) Applied mechanization

The seedbed preparation implement were aggregated with a wheel tractor of installed engine power of 1oo HP. The aggregates roller-cultivator-roller - planter and disc-harrow - planter can achieve the working speed of 9 km/h, and utilize 7o% of the gross working time for productive work. The working performance of these aggregates with the 4-row planter is 1.76 ha per hour of gross working time, and 2.65 ha with the 6-row planter. The aggregate planter unit with tines before the seed opener has the working speed of 7 km/h and utilizes 7o% of the gross working time. The performance with the 4-row planter is 1.37 ha/h of gross working time, 2.o6 ha with the 6-row planter, and 2.74 ha with the 8-row planter.

The seedbed preparation with combined implement is carried out as a separate operation, and so is the sowing with the 8-row planter. The working speed of both operations is 1o km/h, and the utilisation of gross working time is 9o% in seedbed preparation and 7o% in sowing. The aggregate performance in seedbed preparation is 4.5o ha/h of gross working time, and 5.92 ha in sowing with the 8-row planter.

C) Changes in the soil

Expecting that the various mineral fertilizer doses, applied in the trial, in combination with various ways of seedbed preparation could effect some changes, primarily in the chemical soil complex, detailed chemical analyses were made of the soil samples taken from the experimental area, both at the beginning and at the end of the experimental period. It was kept in mind that the experimental period was relatively short to determine the changes with certainty. This also applies to the changes in the physical soil complex. The results are partially presented in Table 1. They basically indicate, that there were mainly no significant changes of the chemical properties. There was a certain effect of the fertilizer doses applied, while there was no effect of the various ways of seedbed preparation and if it appeared in combinations it was obviously the result of fertilizing. However, at the end of the three-year period, positive changes were recorded in most of the studied properties, regardless of the treatment, which points to the conclusion that they were mainly due to the applied agrotechnical measures. This isparticularly evident in the increased contents of available phosphorus and potassium and higher base saturation.

Although the changes in other physical properties of the soil (porosity, water and air holding capacities, specific weight and current moisture) were followed in the trial, only the results of measuring the mechanical soil resistance are given (Table 1). It was primarily influenced by the moisture regime, dropping with the increase of current soil moisture and vice versa. The resistance also showed certain oscillations due to the studied factors. The effect of seedbed preparation practices was direct here, while the effect of fertilizing could have been only indirect, for instance through the degree of the root system development, which can again influence the degree of soil compactness.

DISCUSSION AND CONCLUSIONS

The obtained results confirm that it was correct to choose maize for this kind of investigations, because of its economic and other importance in this country and a very intensive system of agrotechnical measures, which allows certain rationalization. The results also show that it is necessary to evaluate the activity and function of each member in the soil-plant-climate system. The climatic and edaphic conditions of the region favour the growing of maize, but in case of greater climatic aberrations, which do happen, the unity of the mentioned system is disturbed, either by the indirect effect of the climate upon the plant, through the soil, or by its direct effect. Such climatic aberrations were actually present in the course of the trial, particularly in its second year. This was, however, a good side of the investigations, for the functioning of the applied practices could be observed from a wider aspect.

If the effect of the investigated factors is evaluated, the significance in soil tillage was incomparably less marked than in fertilizing. The obtained results still give priority, though not absolute, to the seedbed preparation with combined implement. The yields in the other treatments, though varied, were more or less at the same level, including the direct sowing into the furrow. It is an important finding that the direct sowing into the furrow is possible on this soil type without greater risks for the yield, especially in case of good tilth due to low winter temperatures, probably with certain advantages in wet years. Taking apart the technological-exploitative side of the problem, all the four ways of seedbed preparation, or their combinations with medium or high fertilizing, can be regarded as almost identical. This especially applies to the speed of sowing directly into the furrow, as a prerequisite for ensuring a uniform and optimal plant density of maize. Mention should be made of the very important fact, valid for all the methods of seedbed preparation, that it can be successfully carried out in one run, thus increasing the efficency of the tillage and reducing unnecessary treading of the soil. If the possibility of a simultaneous performance of several operations (seedbed preparation, starter fertilizing, sowing, herbicide application and probably some others) is added to this, the advantages are evident. At the same time, the investigations point to the possible omission of all the practices in the growing period of maize without risking a drop of the yield, but this requires separate investigations.

The yield level was neither limited by the fact that it was actually monoproduction of maize.

The following conclusions can be drawn:

1. In seedbed preparation for maize, grown on lessivé brown soil on sandy substrata, there was no marked advantage of any of the investigated treatments. Even direct sowing into the furrow is possible, as it ensures the same yield as that achieved by other ways of seedbed preparation.

2. The effect of fertilizing was significant. In relation to the different ways of seedbed preparation, fertilizing was dominant.

3. The seedbed preparation by combined implement, in combination with medium or high fertilizer doses, seems to be the most acceptable for the practice.

4. Effected by the complex of the performed agrotechnical measures, positive changes occurred, primarily in the pedochemical complex.

5. A realistic evaluation of the obtained results should, by all means, take into account the fact that is a question of exploiting anthropogenized soil reserves, which have been created throughout decades, even centuries, in the long run of agriculture.

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DIRECT DRILLING (ZERO TILLAGE) AND SHALLOW CULTIVATION ON A RANGE OF SOILS IN THE UNITED KINGDOM

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ABSTRACT

In the experiments in the U.K. here reviewed, direct drilling, shallow or deep tine cultivation and ploughing have resulted in similar yields of spring barley and winter wheat on well structured soils where suitable weed control and agronomic procedures have been adopted. Emphasis is now being given to the effect of reduced cultivation on clay soils and on those which are structurally weak, where greater problems may occur. Although soils are more compact after direct drilling, the development of surface tilth, increased aggregate stability, cracking, greater earthworm activity, and similar levels of oxygen in the soil have been observed.

Introduction

When suitable herbicides became available, especially paraquat in 1961[13], numerous experiments in many countries were carried out in which direct drilling was compared with ploughing. In Britain before 1970, about 60 comparisons of direct drilling and ploughing were made for both spring barley and winter wheat, sometimes in experiments which lasted several years[5]. These experiments were carried out mainly by Imperial Chemical Industries Limited and by the Ministry of Agriculture, Fisheries and Food. In some the yield after direct drilling was satisfactory, but on average it was about 10% less than after ploughing. Usually the reasons for lower yields were not known. More recently experiments have shown little difference between direct drilling and ploughing. The reasons for lower yield in the earlier years included grass weeds, slug damage, problems with drilling and probably lack of experience with the newer techniques[5].

Thus the objective of our initial experiments which began in 1969 in co-operation with the Weed Research Organization was to study the effects of alternative methods of cultivation on the growth of spring barley and winter wheat on land which presented few problems when under normal cultivation (Table 1). The treatments were direct drilling, cultivation with tined implements at 7 or 15 cm depth, and ploughing.

After satisfactory results with direct drilling on these soils, and because the simpler methods of cultivation were being increasingly used by farmers in the United Kingdom[1,8] it was considered appropriate at Letcombe to investigate the feasibility of reduced cultivation and the possible long-term effects on soil conditions on soils which were more difficult than previously used, either through high clay content and restricted drainage, or through structural instability (Table 1). The possibility of using reduced cultivation methods on such soils is of particular interest, at least in our country, because the number of working days is often small.

TABLE 1 SOILS USED IN CULTIVATION EXPERIMENTS

Soil group* U.K. Classification	Soil group* European Units	Texture	General Characteristics	Commenced
Argillic brown earth	Orthic Luvisol	Sandy loam	Mainly well drained	1969**
Rendzina	Rendzina	Silt loam over chalk	Well drained	1970**
Calcareous pelosol	Verti-calcaro gleyic Cambisol	Clay loam	Slowly permeable, well structured	1972**
Argillic brown earth	Orthic Luvisol	Silt loam	Well drained weak structured	1974
Stagnogley	Verti-eutric Gleysol	Clay (2 sites)	Poor drainage+	1974

* Information from D Mackney, Soil Survey of England and Wales.
** Joint Project with Weed Research Organization.
\+ These sites have been artificially drained.

Crop Establishment and Grain Yields

On the well-structured soils the mean grain yields of spring barley and winter wheat over the period 1969-75 were similar in all treatments (Table 2), although rainfall and yield varied greatly between years. For example, on the sandy loam the soil moisture deficit at the end of June varied from 0 to 90 mm, and in the autumn and winter of 1974-75 rainfall was about 40% above average. When direct drilling caused a lower yield than ploughing by 5% or more, it was always in the first year of an experiment and has been often associated with a reduction in plant population (Table 3). The reductions in plant population were not so great that they would have been expected to have a large effect on yield with conventional cultivation; it seems that direct-drilled crops may have a reduced capacity to compensate for low plant density.

TABLE 2 RELATIVE GRAIN YIELD OF SPRING BARLEY AND WINTER WHEAT AFTER DIFFERENT CULTIVATION TREATMENTS, 1969-1975*

	Yield of grain after ploughing (t/ha)	Yield relative to that after ploughing: Tine cultivated, Deep	Tine cultivated, Shallow	Direct-drilled	Number of experiment-years**: Sandy loam	Silt loam over chalk	Clay loam	Total
Spring barley	4.54	1.01	1.02	1.00	5	4	3	12
Winter wheat	5.04	1.05	0.95	0.97	5	1	3	9

* Source of information references (4) (10).
** An experiment-year is an individual year of each experiment.

The difficulty in establishing adequate plant populations with direct drilling may be due to several factors. These may include the greater compaction in direct-drilled soils, to which reference is made later, or the limitations of drilling equipment.

Plant establishment may also be impaired when seeds germinate close to decomposing crop residues, especially in wet conditions. The recommended practice for successful direct drilling in the U.K. is to remove surface residues of the previous crop; this is normally achieved by burning, but in wet weather complete removal may be impracticable. In the wet autumn of 1974 in some crops where the plant population was very low, it was found that seeds had been pushed into the soil by the triple-disc drill in contact with unburnt straw. Seeds had usually germinated but died after the radicles had emerged[11]. Laboratory studies show this was due to soluble decomposition products, including acetic acid, caused by microbial activity[15].

TABLE 3 PLANT POPULATION AND GRAIN YIELD AFTER DIRECT DRILLING RELATIVE TO THAT AFTER PLOUGHING WHEN YIELD AFTER DIRECT DRILLING WAS REDUCED BY 5% OR MORE*

Experiment	Crop	Direct-drilled relative to ploughed: Plant population	Grain yield
Sandy loam	Spring barley	0.92	0.85
	Winter wheat	1.05	0.88
Silt loam over chalk	Winter wheat	0.94	0.94
Clay loam	Winter wheat	1.42	0.91
	Spring barley	1.02	0.89
Silt loam	Spring wheat	0.55	0.90
Clay (Denchworth series)	Winter oats	0.71	0.92
Clay (Rowsham series)	Winter oil-seed rape	1.04	0.95

* Source of information references (4) (9) (10) (12) (16).

Effects on Soil Conditions

Our most detailed observations have been made on the clay loam; of the soils used in the earlier experiments this was most likely to present the greatest limitations to successful direct drilling; the comments which follow refer to this soil except when otherwise stated.

Compaction and Soil Strength Measurements of bulk density and resistance to a cone penetrometer, in the upper 20 cm, show that the soil was more compact in the direct-drilled treatment than after ploughing; the main changes occurred in the first year. Although early root growth was sometimes restricted after direct drilling, the effect diminished within a few weeks. The bulk density and penetrometer resistance in the tine-cultivated areas were intermediate between direct drilling and ploughing.

Soil Structure and Stability Friable surface tilths have developed on the direct-drilled treatment, especially in the autumn. Although this self-mulching property is generally associated with soils containing montmorillonite clay, it is also influenced by other factors, including the organic matter content. The presence of the surface tilth has favoured rapid germination of seed sown in autumn, and the tilth may have been a significant factor contributing to the success of direct drilling on this soil. However, wet conditions lead to slaking of the aggregates, which may almost disappear in a wet winter. An increased content of organic matter has been found in the upper 2.5 cm after repeated direct drilling, and this has been associated with increased stability of soil aggregates in this zone. Of the soils on which we are working, only the silt loam which is very weakly structured, and readily slakes has shown no tendency to greater stability of the aggregates or to form a friable tilth. On the sandy loam the development of this surface tilth became particularly pronounced by the fifth year of direct drilling.

It is evident from the improvements of soil structure often observed under permanent grassland[14] that numerous natural processes can lead to the improvement of soil conditions when soil is undisturbed. Some of these are discussed by Russell and Goss[17]. In the very dry summer of 1975 cracking in the clay soils was much more pronounced than usual, exceeding 100 cm in depth in the direct-drilled plots, but to a lesser depth in ploughed land. More earthworms have been found after repeated direct drilling, and the ratio of total number on direct-drilled to that on ploughed plots has increased with time (Table 4), although the actual numbers have varied between seasons depending on environmental conditions such as soil moisture. In some soils increased numbers of continuous channels have accounted for more rapid drainage of gravitational water after direct drilling[7], and roots freely grown down earthworm channels.

TABLE 4 NUMBERS OF EARTHWORMS IN A CLAY LOAM AFTER DIRECT DRILLING AND PLOUGHING (Samples were collected in the autumn, before primary cultivation for spring barley)

	Direct-drilled (numbers per m^2)	Ploughed	Ratio of direct-drilled:ploughed
After first year, 1973	145	110	1.32
" second " , 1974	345	218	1.58
" third " , 1975	230	98	2.37

Aeration These changes in soil structure and earthworm activity may account for the fact that in spite of greater compaction of the clay loam soil, the oxygen content has usually been as great in direct-drilled land as in ploughed land, even when the rainfall pattern varied considerably (Fig 1).

Nitrogen supply More nitrogen fertilizer or different time of its application is sometimes, but not always, needed for maximum yield of direct-drilled crops than those grown after conventional techniques (2,5,18). However the reasons are uncertain, and different explanations are likely in different circumstances. In our work on the clay loam, the nitrate content of the soil was consistently lower (by a factor of 2 to 3) during a dry winter (1972-73) between December and March after direct drilling than after ploughing[6]; the oxygen content of the direct-drilled and ploughed areas was then comparatively high (Fig 1), and there was no evidence of denitrification. Moreover, losses of nitrate by leaching were probably insignificant; it seems probable that the lower nitrate content of the direct-drilled treatment was due mainly to a decreased rate of mineralization of soil organic nitrogen (6). In the next year when rainfall was higher the lower nitrate content in the direct-drilled soil in early winter was associated with lower oxygen (Fig 1) and there was evidence of greater denitrification (Table 5). In the third year (1974-75), when winter rainfall was exceptionally high, the concentration of oxygen in the soil declined rapidly in both cultivation treatments, and little nitrate was found, being presumably lost by denitrification.

FIGURE 1 OXYGEN CONCENTRATION AT TWO DEPTHS IN A CLAY LOAM (EVESHAM SERIES)

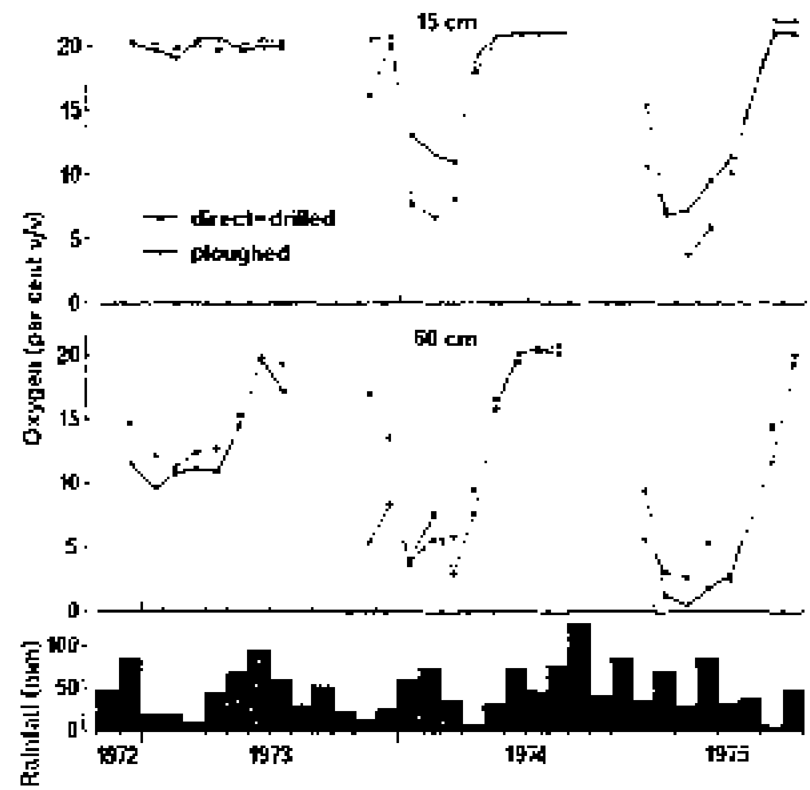

TABLE 5 CONCENTRATION OF NITRATE-N IN SOIL WATER AND OF NITROUS OXIDE IN THE SOIL ATMOSPHERE IN A CLAY LOAM (EVESHAM SERIES)*
(For rainfall see Fig 1)

	Depth (cm)	Nitrate in soil water (μg N ml^{-1}) Direct-drilled	Ploughed	Nitrous oxide in soil atmosphere (ppm) Direct-drilled	Ploughed
November to December 1973	15	34	52	7	1
	30	12	13	83	3
	60	2	2	78	8
January to May 1974	15	32	32	42	18
	30	26	32	29	38
	60	4	9	70	37

* Source of information reference (5).

Conclusions

On well structured and drained soils a wide range of cultivation techniques can produce satisfactory yields; and simplified cultivation can save labour and energy. Furthermore, the shorter time required to sow a crop may result in improved timeliness of sowing, and may make it possible to establish a larger area of higher yielding autumn crops of cereals or oil-seed rape; when this is the case, reduced cultivation may be particularly beneficial on heavy soils, but at present there is insufficient information on the exact conditions when direct drilling will be successful.

It is obviously important that the factors limiting the effectiveness of different cultivation methods should be properly identified. In much past experimental work in which tillage methods were compared, the results may have been influenced by inadequate weed control, a problem which can be expected to decrease with improved herbicides. From the point of view of soil disturbance, any rigid distinction between different forms of reduced cultivation may be misleading, since the various techniques represent a continuum; the amount of soil disturbance caused by direct drilling into a friable soil may not differ greatly from that caused by shallow tine cultivation. Direct drilling represents the most extreme form of reduced cultivation, and therefore is valuable for research. The extent to which it can be eventually regarded as appropriate in practice will depend on many factors which can influence its reliability; effects on soil conditions are obviously of great importance.

This paper has been confined to work with which we have been concerned in southern England. There are numerous important inputs by other institutes of the Agricultural Research Council, including the Weed Research Organization, by the Ministry of Agriculture, Fisheries and Food, by universities and by commercial companies. Finally we acknowledge the valuable co-operation of Mr J.G. Elliott of the Weed Research Organization with whom we worked closely in the earlier experiments.

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INFLUENCE OF TILLAGE AND DRAINAGE SYSTEMS ON PHYSICAL CONDITIONS FOR LOAM-CLAY SOILS CULTIVATION

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ABSTRACT

An experiment carried out on loam-clay soils in Central Italy to evaluate the influence of tillage and drainage systems on winter wheat growth and yield has shown that minimum-tillage may reduce yield of grain in comparison to ploughing as a consequence of an increase of soil compaction.

Underground tyle drainage seems to favour a reduction of runoff without decreasing water storage to a damaging limit for winter wheat growth and yield.

INTRODUCTION

A large extencion of loam-clay soils in Central Italy are originated on Pliocenic marine sediments.

They present poor physical conditions in relation to plant establishment and growth, beside an high susceptibility to soil erosion (mainly mass erosion).

Some mineralogical and physical parameters of the loam-clay soils of the Era Valley (Pisa) are reported in table 1.

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The presence of a large amount of expansive minerals in the clay fraction (<0.002 mm) explains the high porosity, plasticity and water retention capability shown by these soils.

Their behaviour - as related to the Era Valley climate -, would be cleared by comparing the mean precipitation summarized in a Bagnouls-Gaussen diagram, with the ETP monthly values calculated by Thornthwaite formula (figure 1).

Precipitations are concentrated in the autumn and spring seasons, while a prolonged dry period occurs between May and September.

Soil dehydratation in the dry period favours volume contraction followed by cracking. At the same time cohesion and soil impedance to root penetration would be enhanced.

Cracking, however, would increase macroporosity and reduce bulk density, mainly in the upper soil layer (Lulli & Ronchetti(4)). Sfalanga & Rizzo (5) have shown that the direction of cracking changes from vertical to horizontal, passing from soil to parent material.

Macroporosity due to cracking represents the preferential way of water recharge in the soil during the autumn season in undisturbed soils (sods).

Soil water recharge in autumn is very important for the cultivation of these loam-clay soils, being responsible for water storage to be utilized in the period of rainfall shortage (as compared to ETP), beginning around middle April.

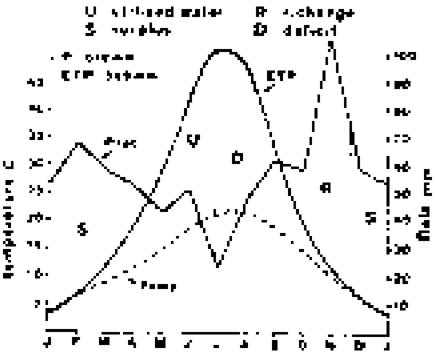

Fig 1 Bagnouls-Gaussen diagram and Thornthwaite ETP values at Y-carello experimental farm in the Era valley

To increase water storage, to be utilized by the zone common rotation represented by winter wheat / mixed ley, the best system of tillage devised up today is summer ploughing up/down the slope using powerfull tractors, sometime integrated by drainage surface channels or grassed waterways, normal to the slope line, to reduce runoff velocity.

Nevertheless, this kind of soil management make the land subject to mass erosion and landslip, during late autumn/winter season, in rainy years.

Another peculiar characteristic of these loam-clay soils is self-mulching, represented by the formation of a layer of fine aggregates on the soil surface. Self-mulching-which could attain a deepness from 1 to few centimetres-is probably caused by the consistent variation of temperature and relative humidity between day and night in the summer period.

In relation to cracking and self-mulching phenomena in the Era Valley, it was hypotized that winter wheat cultivation would be possible without ploughing the soil, by applying minimum-tillage practices, providing that: (i) water infiltration and recharge in the soil would be guaranteed by cracking porosity; (ii) an appropriate seed-bed would be provided by summer self-mulching of the soil; (iii) weeds control would be possible by the use of herbicides to eliminate either natural grasses or large leaf species.

For soil stabilization against mass erosion and landslip, the use of an underground tyle drainage system was devised as the best way to eliminate the excess of water in the soil during the winter rainfall surplus.

EXPERIMENT LAYOUT

To compare the influence of different systems of soil management on winter wheat growth and yield, as related to soil physical conditions, an experiment was carried out at the Vicarello Experimental Farm in the Era Valley (Pisa) on loam-clay soil formed on Pliocenic marine sediments (1).

The following soil treatments were factorially combined:

Tillage treatments

(a) Minimum-tillage performed by desherbage with Paraquat followed by disking.

(b) Ploughing of the soil in Summer followed by disking.

Drainage treatments

(c) Underground drainage with PVC tyles 0.8 m deep and 8.0 m apart.

(d) Absence of a drainage system.

The plots receiving treatments ac, ad, bc and bd were equipped for the measure of runoff, drainage discharge and erosion.

A detailed soil survey by Lulli, Ronchetti and Tellini (3) acknowledged the presence in the experimental plots of 3 series of soil denominated "Pegolina" (Entisol), "Mattaione" (Inceptisol) and "Type C" (Vertisol) (table 2).

[illegible]

The relative areas of the different soil series in every plot were mapped.

Sampling for vegetation and yield measurements were randomly performed in each area.

Test crop, represented by cv "Funo" winter wheat, was sown for several years in November and harvested in July.

Weeds control was realized uniformly on all the plots by pre-emergence Teburtin (Ingram 50) against grass weeds, and post-emergence Ioxinyl + MCPP (Certrol H) against large leaf weeds.

RESULTS AND DISCUSSION

Hydrological and Physical soil data (table 3) show that tillage and drainage treatments have influenced to a large extent soil conditions in the different plots.

Ploughing would increase cracking and reduce bulk density in comparison to minimum-tillage. Moreover, the impedance to root penetration is consistently higher in the minimum-tillage plots during the Spring season while the differences disappear during the Summer.

Runoff is remarkably enhanced in the plots without tyle drainage. Drain discharge on the other hand is larger on minimum-tillage in comparison to ploughed plots.

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The yearly amount of soil eroded by runoff is generally small, but evidently higher on the ploughed plots.

Soluble salts exportation by runoff appears to be reduced in presence of tyle drainage.

Winter wheat root & shoot growth (table 4) - on which some preliminary data have been previously published (2) - seems to be favoured by ploughing the soil, in comparison to minimum-tillage. Moreover, small differences indicate

	[illegible] (1)	[illegible] (2)	[illegible] (1)	[illegible] (2)	[illegible] (1)	[illegible] (2)	[illegible] (1)	[illegible] (2)
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7.50	[illegible]	[illegible]	[illegible]
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that, in absence of drainage, root and leaves biomass increases while culm height decreases.

Winter wheat grain yield results significantly enhanced by ploughing in comparison to minimum-tillage (table 5).

Also, the presence of underground tyle drainage seems to increase the winter wheat grain yield more consistently on the Mattaione than on the Pegolina series of soil (figure 2).

The wheat grain yield in the ploughed plots during different years of trial results almost uniform. In the minimum-tillage plots, instead, there is a large variability with a

[illegible]

	Year [illegible]		Year [illegible]		Year [illegible]		Years [illegible]	
	P	M	P	M	P	M	P	M
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Fig.2 Interaction between drainage system and soil series on wheat grain yield

consistent increase of yield from the first to the third year of cultivation (figure 3).

It was hypotized that weeds control by the herbicides may have been influenced by climatic condition peculiar to each year. In any case, the controlmay have been better in the ploughed than in the minimum-tillage plots.

Hydrological variations between treatments, and specifically ET differences, do not seem to be responsible for the differences of wheat growth and yield observed in the plots (Figure 4).

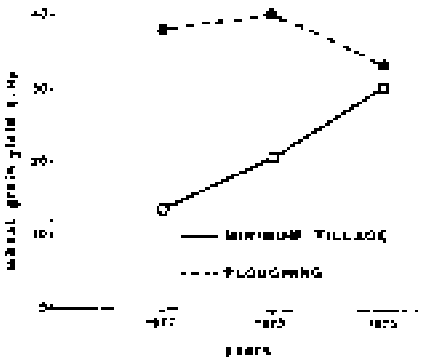

Fig.3 Interation between tillage and years on wheat grain yield

In fact, water shortage begins in middle April, so that the amount of water storage in the soil appears to be sufficient for ET requirements, during the final stages of wheat ripening, either in the ploughed or in the minimum-tillage plots.

Clearly, minimum-tillage garantees a sufficient recharge of soil water for wheat cultivation, through cracking natural macroporosity.

Also self-mulching seems to provide a good natural seed-bed for wheat germination and emergence of seedlings. The data of wheat growth at the tillering stage confirm what above, being not detectable differences on wheat root & shoot growth at such stage.

Fig.4 Influence of ET on wheat grain yield as related to tillage and drainage system

Starting from tillering time, wheat plants begin to suffer the increasing soil compaction caused by soil dehydratation following reduced rainfall and increased ET.

Root elongation appears consistently impeded by the increasing soil resistence to penetration and bulk density (figure 6).

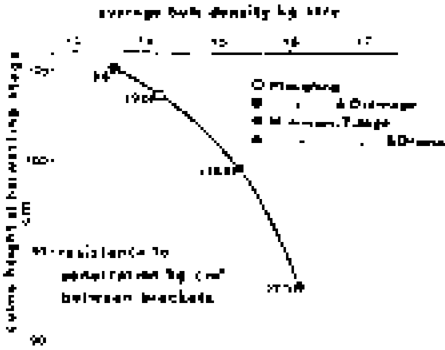

Fig 5 Relation between bulk density and culms height at harvesting time

Moreover, also wheat culms appear to be shortened by the effect of the increasing soil resistence to penetration and bulk density, in relation to the different tillage and drainage treatments (figure 5).

It appears clearly that the enhanced soil compaction - in the minimum-tillage in comparison to ploughed plots - is the more effective cause of winter wheat growth and grain yield reduction (figures 7 and 8).

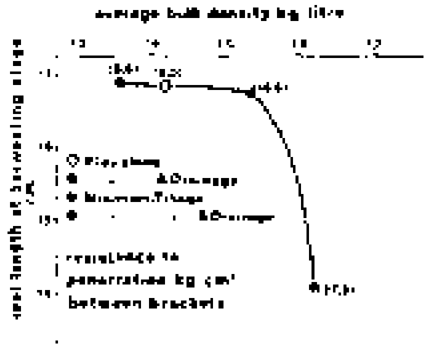

Fig. 6 Relation between bulk density and root elongation at harvesting time

Conclusively, it could be said that in these loam-clay soils a consistent decrease of winter wheat growth and yield may be expected by the application of minimum-tillage in comparison with the normal ploughing up/down the slope, mainly as a consequence of an increase of soil compaction.

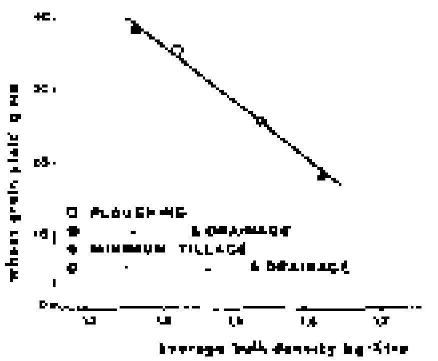

Fig 7 Relation between wheat grain yield and soil bulk density

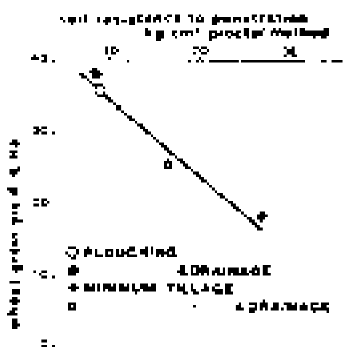

Fig 8 Relation between wheat grain yield and soil resistance to penetration

In any case, soil underground drainage would enhance the stability of the given loam-clay soils by the control of run off and erosion, without reducing the amount of water recharge and storage at an extent in which plant growth and yield may by negatively influenced.

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INFLUENCE OF ACTIVE IMPLEMENTS ON SOME PHYSICAL PROPERTIES OF SOILS AND CROP YIELDS.

I.Dechnik, St.Tarkiewicz

ABSTRACT

The influence of the Polish plough-miller as an active cultivation implement on soil strength,moisture, total porosity, bulk density and crop yields was studied.

The studies were conducted in the years 1973-1975 on brown soil formed from loamy sand. Cultivation with the mould-board plough was taken as control.Experiments were performed in four replicas with potatoes, spring barley and rye using trifield rotation.

The use of the plough-miller was found to cause a decrease in strength and an increase in total porosity of the cultivated soil;however,it did not vary soil moisture content in comparison with cultivation with the mould-board plough.Cultivation with the plough-miller has a favourable effect on the yield of the plants studied.

INTRODUCTION

Investigations concerning the influence of active cultivation implement on physical properties of soils and crop yields have been conducted in Poland for several years. Their purpose is to determine the maximum use of these implements in basic soil cultivation, which leads to replace the traditional cultivation implements of soil such as mould-board plough, harrow and cultivator.

According to some authors [1,2,3], the use of active implements should reduce the number of suplementary tillage and,in consequence,reduce soil compaction due to the decreased number of tractor operations in the field.

The problem, however,is whether the use of active implements does not worsen physical properties of soils and crop productivity.

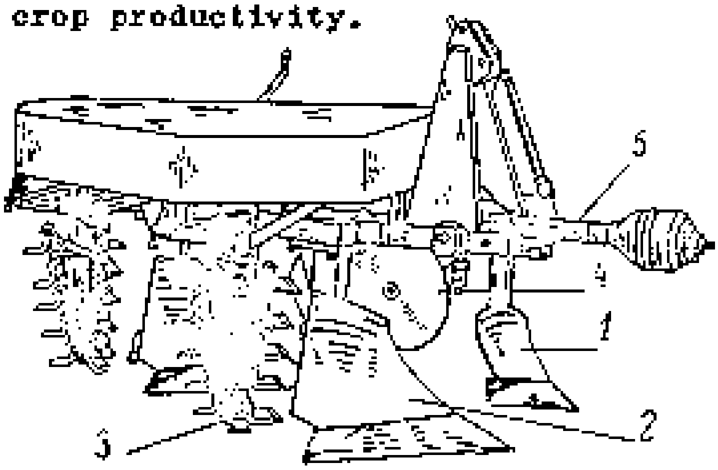

Fig.1 The Polish plough-miller PFz-235.
1.share skin coulter
2.furrow openning body
3.knife scarifier
4.disc coulter
5.cardan shaft

Our studies aimed at evaluation of soil cultivation with the plough-miller [a plough combined with active and static working elements] as compared with cultivation by using the mould-board plough as the standard [fig.1].

METHODS

Experiments were conducted on brown soil formed from loamy sand, in the years 1973, 1974 and 1975 [tab.1].

TABLE 1. Mechanical composition, physical and chemical properties of the soil.

Depth cm	Percentage of mechanical fractions in mm				Bulk density $g.cm^{-3}$	Specific gravity $g.cm^{-3}$	Specific surface area $m^2\ g^{-1}$	Humus %
	1,0–0,1	0,1–0,02	0,02	0,002				
0–30	60	24	16	6	1,51	2,60	6,8	1,1

The experiment design comprised comparison of strength, moisture, total porosity, bulk density of soil and crop yields in two combinations of cultivation [tab.2] with three variances of trifield rotation, in four replicas [tab.3].

TABLE 2. Cultivation measures in combinations.

Cultivated plants	Ploughing with plough-miller		Ploughing with mould-board plough	
	cultivation measures	month	cultivation measures	month
Potatoes	winter ploughing 28 cm deep	IX	winter ploughing 28 cm deep	IX
	fertilizing NPK harrowing planting	V	fertilizing NPK harrowing planting	V
Spring barley	winter ploughing 24 cm deep	XI	winter ploughing 24 cm deep	XI
	fertilizing NPK harrowing sowing	III	fertilizing NPK harrowing sowing	III
Rye	first ploughing 12–15 cm deep	VIII	first ploughing 12–15 cm deep	VIII
	ploughing for sowing 24 cm deep	IX	ploughing for sowing 24 cm deep	IX
	sowing harrowing	X	sowing harrowing	X

Years	Rotation		
	plot I	plot II	plot III
1973	potatoes	spring barley	rye
1974	spring barley	rye	potatoes
1975	rye	potatoes	spring barley

TABLE 3.
Crop rotation.

Soil strength was measured with a manual spring-penetrometer every year, in April, June, August and October. Soil moisture [in % by weight] and bulk density [in $g.cm^{-3}$] were determined by the oven-dry method and total porosity, by air picknometer.

RESULTS

Soil strength and moisture content.

Soil strength was higher in the summer months [June, August] under all plants studied regardless the cultivation implements used [fig.2].

However, it was lower in the soil cultivated with the plough-miller in comparison with the strength of the soil cultivated with the mould-board plough almost in all months [fig.2]. These differences are distinctly higher in the soil under cereals than under potatoes.

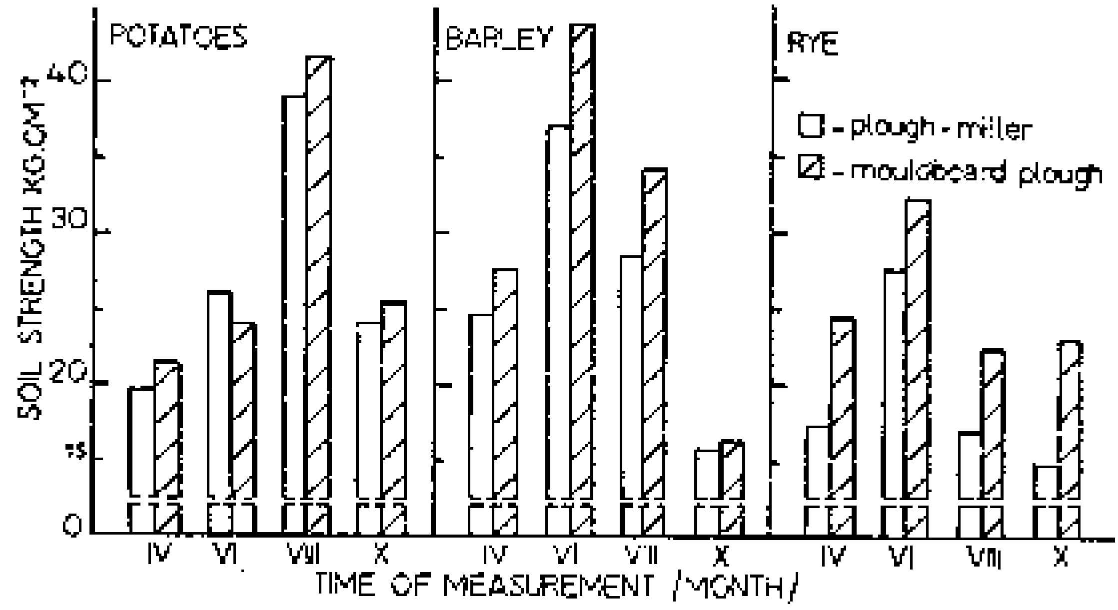

Fig.2 The influence of compared cultivation measures on soil strength [mean value of 3 years].

The differentation of strength of the soil studied is related to changes in moisture content of this soil, particulary in the vegetation period. The strength of the soil cultivated with the plough-miller is considerably influenced, beside moisture content, by other conditions. Better crumbling and displacing of soil in the arable layer cultivated with the plough-miller as compared with mould-board plough, is, among others, one of the most important factors.

In our studies, the use of the plough-miller did not distinctly effect the values of moisture content of the soil in comparison with mould-board plough cultivation [fig.3]. However, when soil moisture content decreased below 7 % it was higher [>2%] in the soil with plough-miller cultivation.

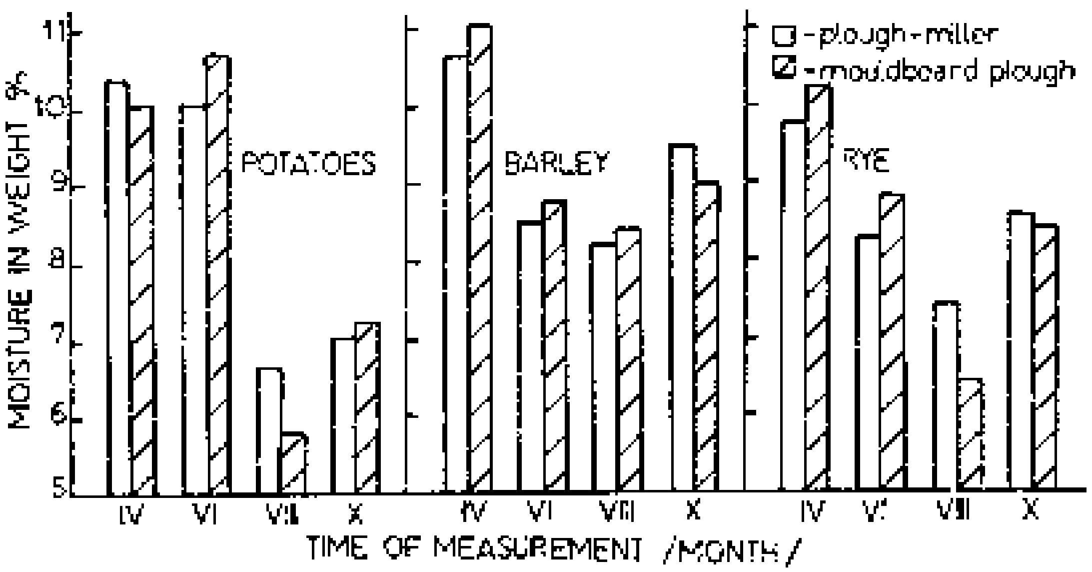

Fig.3 The influence of compared cultivation measures on moisture content, in % by weight [mean value of 3 years].

Total porosity and bulk density.

Total porosity was always lower in April and higher in October irrespective of the cultivation implements used [fig.4]. But the values of bulk density of the soil

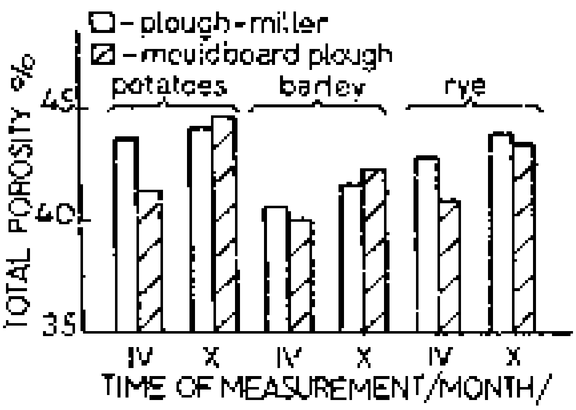

Fig.4 The influence of compared cultivation measures on total soil porosity in % [mean value of 3 years].

in these periods were quite reverse, although the variation of this characteristic was not significant in the period studied [fig.5].

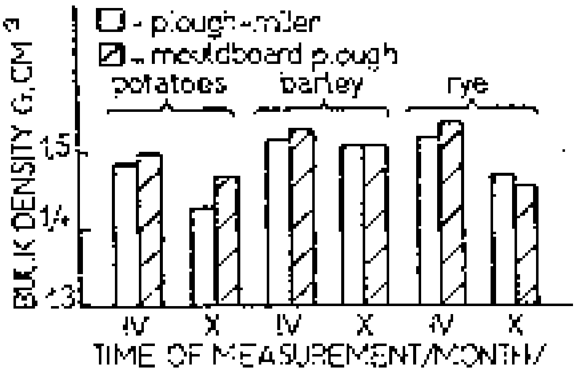

Fig.5 The influence of compared cultivation measures on soil bulk density in $g.cm^{-3}$ [mean value of 3 years].

At the begining of the vegetation period total porosity of the soil cultivated with the plough-miller was slightly higher than that of the soil cultivated with the mould-board plough. Particularly, significant differences [2%] were found under potatoes and rye [fig.4].

In autum, total porosity of the soil did not vary in relation to the cultivation implements used. Consequently, the increase of total porosity of the soil caused by using the plough-miller is short-lived in relation to mould-board plough cultivation. The soil, being crumbled and mixed better by the active elements of the plough-miller, deposits itself faster during the vegetation period and its total porosity approximates the level of the porosity of the soil cultivated with the mould-board plough.

Crop yields.

Crop yields of the soil cultivated with the plough-miller were slightly higher than those of the soil cultivated with the mould-board plough [tab.4]. This tendency

TABLE 4. Crop yields of plants in $q.ha^{-1}$.

Cultivation measure	Cultivated plants		
	Potatoes	Spring barley	Rye
Plough-miller	261	42,5	37,7
Mould-board plough	260,5	41,4	36,9

is correlated with more favourable physical properties of the soil cultivated with the plough-miller. This concerns particularly higher values of total porosity and lower strength of the soil at the begining of plant growth.

CONCLUSIONS

1. The use of the plough-miller in basic cultivation causes a decrease in soil strength and an increase in total porosity of brown soil formed from loamy sand in comparison with these properties of the soil cultivated by using the mould-board plough.

2. Cultivation with the plough-miller as compared with mould-board plough cultivation did not vary the soil moisture content.

3. The replacement of the mould-board plough by the plough-miller in basic cultivation has a favourable effect on yields of potatoes, spring barley and rye of the soil studied.

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THE INFLUENCE OF LONG - TERM REDUCED TILLAGE IN TWO CROP ROTATION ON THE YIELD OF WHEAT AND MAIZE

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ABSTRACT

A research into reduced tillage has been tested for the ten years in a complex experiment. This paper will present the results of reduced tillage effect, ploughing, and, the intensity of fertilization on the wheat and maize yield in eight experiment-years (1967-1974). Besides those results the last 4 experiment-years' results have been separately considered. The results pointed to the following conclusions: Ploughing is preferable to the reduced tillage especially with maize under present soil and climatic conditions. Ploughing in relation to reduced tillage results in higher yield with maize compared with wheat.

The experiment was established in 1966/67 in the Institute of Agricultural Research in Novi Sad with the following experimental variants: disc-harrowing to the depth of 8-10 cm, ploughing to 15 cm, 25, 35 and 45 cm, with 4 fertilization variants: check plot, low mineral fertilizer rate - 178 kg/ha NPK, medium - 260 kg/ha and high rate - 342 kg/ha NPK pure nutrients in relation to 71:62:45; 107:88:65 and 142:115:85. No herbicides were applied in the experiment and the weed control was performed by hand.

The previous results were published a few times (Drezgić et all 1968, 1969, 1972. 1, 2, 3). In this paper the average yield results are going to be presented from eight experiment-years and from the last four years, exept the variant of ploughing to the depth of 45 cm.

BASIC CLIMATIC AND SOIL FEATURES OF THE EXPERIMENTAL REGION

According to long term meteorological observations of the experimental region (the north-east part of Yugoslavia - Vojvodina) the climatic data were as follows: the average annual temperature from 10,9 C, average air temperature in July 21,4 C, in January -1,6 C. Its average temperature fluctuations between July and January from

22,6 C to 23,1 C. The total annual temperature attained to 3... C. And annual precipitation in 1969-1976 to 601 mm.

The experiments were carried out on moderate lime-chernozem type of soil of the following properties: the depth of A humus horizon went to a depth of 60 cm. The horizon AC was at a depth of 60-85 cm, where as under it was loess rich in lime. According to mechanical texture A and AC horizons belounged to clay loam.

In water suspension the pH value was sligthly alkaline (7,7). From a depth of 25 to 40 cm it contained small quantities of lime (1,0-1,6%). Under a depth of 40 cm the soil was rich in carbonate. Is content of humus was moderate (3-3,5%), and likewise the one of nitrogen (0,18-0,16%); available P_2O_5 was 12-14 mg/100 gr soil, and K_2O about 22 mg/100 gr soil. It had satisfactory water-physical properties.

The meteorological conditions varied according to the duration of experimental years especially regarding the amount and distribution of precipitations which reflected on the yield in each experimental year.

RESULTS AND DISCUSSION

The experimental results of the maize are represented on Table 1. and graph 1.

In the eight-years average on the check-plot the ploughing compared with reduced tillage was more advantageous. The differences in yield between reduced tillage and ploughing on the greatest depth of 35 cm amounted to 19,8 q/ha. These differences were greatly reduced by the application of fertilizers and amounted to 10,54 q/ha. on average to the benefit of the deepest ploughing. The effect of mineral fertilizers on the yield height was considerably higher and it was 15 q on an average for all cultivations depth and mineral fertilizer rates.

The results for the last 4 years showed, relating to eight-years average, significant differences between reduced tillage and ploughing. On the check-plot, these differences vary from 26 q/ha to the benefit on the deepest ploughing from 31 cm. When fertilizers were added these differences were less and amounted to 14 q/ha to the benefit of the deepest ploughing.

The effect of long-term reduced tillage (shallow cultivation), various ploughing depth and intensity of fertilization on the yield of maize and wheat.

Tab.1 Yield of maize grain average for eight years - 1967-1974.

Depth of cultivation		Rate of NPK pure nutrients				Average for the depth of cultivation
		0	[illegible] kg	[illegible] kg	[illegible] kg	
Disc-harrowing	[illegible] cm	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Ploughing to	18 cm	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
"	[illegible] cm	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
"	32 cm	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Average for mineral fertilizers		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Yield of grain (average for the last four years 1971-1974)

Disc-harrowing	[illegible] cm	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Ploughing to	[illegible] cm	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
"	[illegible] cm	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
"	[illegible] cm	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Average for mineral fertilizers		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Tab.2 Yield of wheat grain average for eight years - 1967-1974.

Depth of cultivation		0	[illegible] kg	[illegible] kg	[illegible] kg	Average for the depth of cultivation
Disc-harrowing	[illegible] cm	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Ploughing to	[illegible] cm	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
"	[illegible] cm	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
"	[illegible] cm	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Average for mineral fertilizers		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Yield of grain for last four years - 1971-1974

Disc-harrowing	[illegible] cm	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Ploughing to	[illegible] cm	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
"	[illegible] cm	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
"	[illegible] cm	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Average for mineral fertilizers		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

The same results presented on graph.3 were worked out by square regression. These data show clearly the differences between reduced tillage and ploughing on greater depth, however, it indicated that the increased mineral fertiliser rates decreased the effect of ploughing depth.

On table 1 the experimental results are recorded with winter wheat. The results with wheat differ significantly from the results with maize overall the wheat was more affected by the intensity of fertilisation than by the cultivation depth. In the eight years average the difference in the yields between reduced tillage and the deepest ploughing on the check-plot amounted to 1,86 q/ha. However, the yields were slightly reduced by greater ploughing depth by using fertilisers.

In the last 4 years the significance of the ploughing depth has been clearly increased on the check-plot but less by addition of fertilisers. On the check-plot this difference was 6,24 q/ha to the benefit of deeper ploughing whereas this difference has been reduced to 3,06 q/ha by using fertilisers.

On graph 5 the same results are worked out by square regression.

The data of wheat respond on ploughing depth in this experiment differed from the results of our, previous, experiments. The results of the same experiment published in 1981 indicated to the significance of cultivation quality, natural panning and soil compaction but by wheat sowing in the crop rotation as was difficult to obtain because of late maize harvest and short period for soil panning and some other difficulties in seed bed preparation. Under such conditions the deeper the soil cultivation the poorer the quality was and the number of seedlings was reduced.

These observations were in accordance with the results of A.Stranak (5,6), who pointed to the significance of soil compaction for cereals yield.

On graph.6 the parallel experimental results maize and wheat are shown. These results for eight-years average and for the last 4 experimental years average pointed to considerable differences between the two crop types. Reduced tillage compared to ploughing resulted in better wheat yield than maize. Our previous investigations indicated that reduced tillage lead to satisfactory results with wheat after sugar-beet and maize under appropriate climatic conditions. However, ploughing had priority over reduced tillage with maize. (Drezgić et all.6-7). Many factors have to be taken into consideration for a succesful reduced tillage both with wheat and with other cultures and in that regard we agree with E.W.Russel (1974 (8), and other authors who examined that problem fully and specifically in respect of the soil type, climatic conditions and the implements applied.

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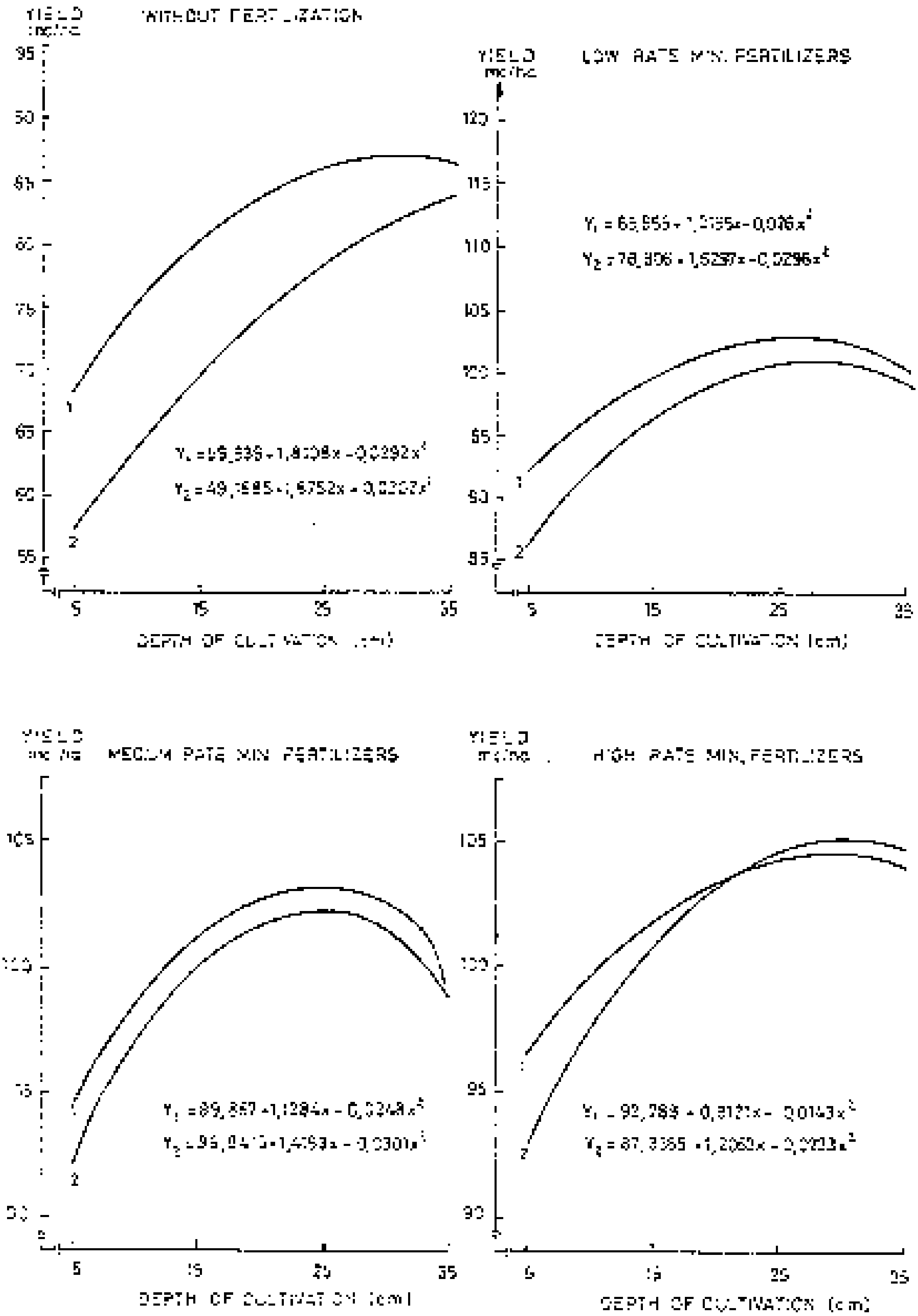
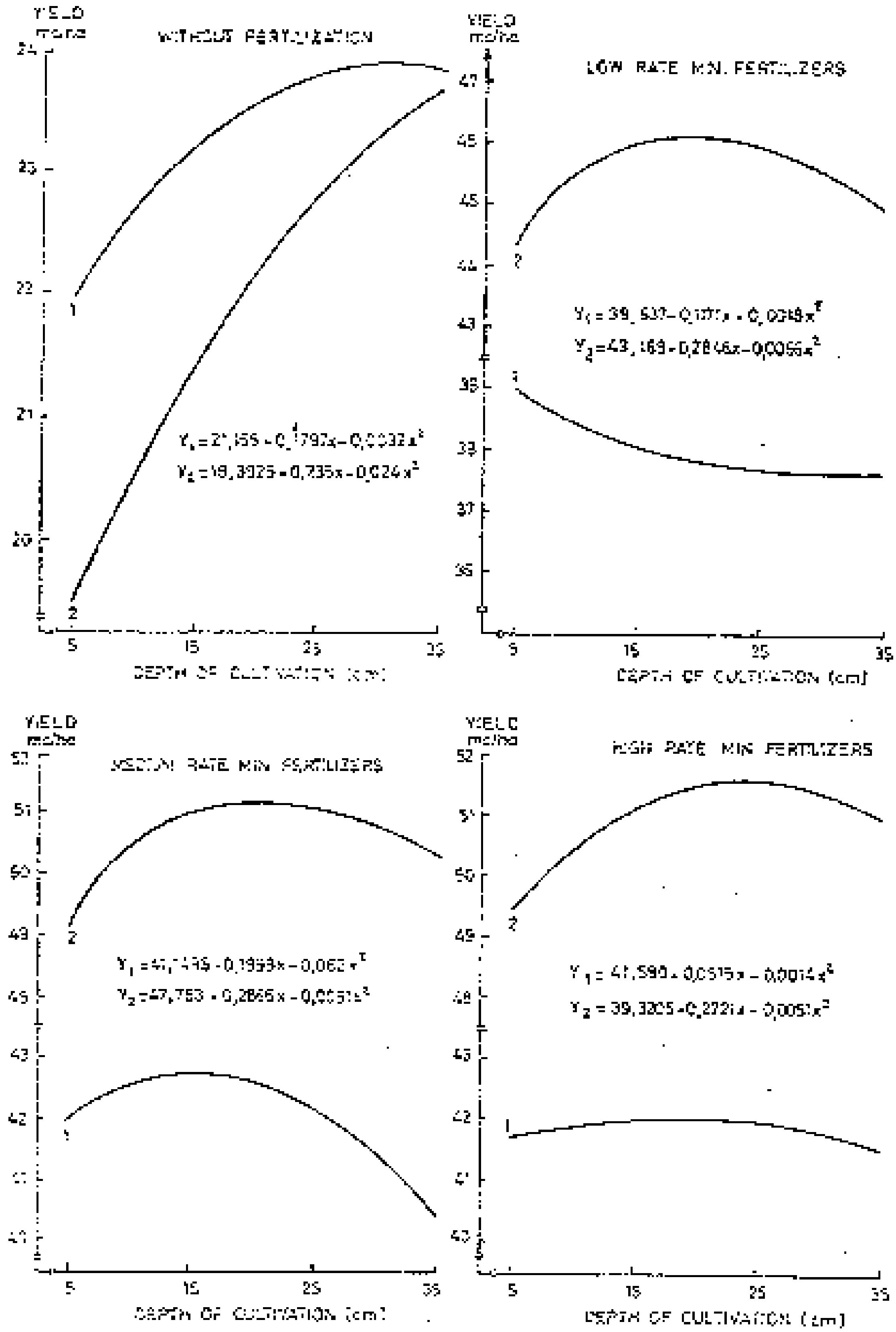
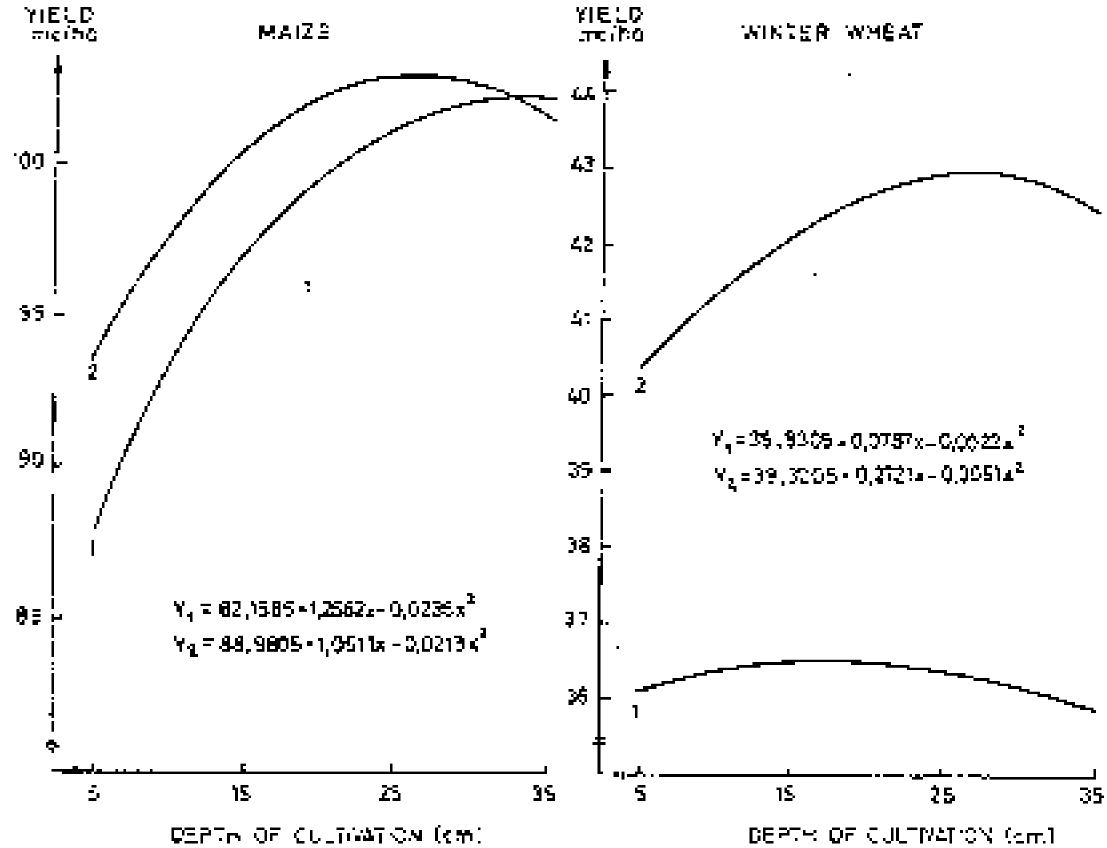
GRAPH 1 THE EFFECT OF LONG-TERM REDUCED TILLAGE (SCHALLOW CULTIVATION), VARIOUS PLOUGHING DEPTHS AND INTENSITY OF FERTILIZATION ON THE YIELD OF MAIZE



GRAPH. 2 THE EFFECT OF LONG-TERM REDUCED TILLAGE (SCHALLOW CULTIVATION) VARIOUS PLOUGHING DEPTHS AND INTENSITY OF FERTILIZATION ON THE YIELD OF WINTER WHEAT



GRAPH 3   THE EFFECT OF LONG-TERM REDUCED TILLAGE (SCHALLOW CULTIVATION), VARIOUS PLOUGHING DEPTHS AND FERTILIZATION ON THE YIELD OF MAIZE AND WINTER WHEAT



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WATER UPTAKE BY WHEAT ROOTS IN TILLED AND UNTILLED LOESS SOIL

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ABSTRACT

The water uptake pattern of wheat roots was investigated in the field with zero-tilled plots and conventionally tilled plots. In both tillage treatments water was absorbed mainly in the soil top layers, where rooting density was high. But when the top layers became dry, the zone of maximum water uptake was shifted to deeper soil layers. The availability of water was strongly dependent on soil moisture tension already in the low tension range (< 1 bar). In tilled soil roots absorbed less water from the 20-30 cm layer with a small porosity as compared to adjacent layers with higher porosities.

INTRODUCTION

The water uptake and transpiration of plants will depend on the meterological conditions, the hydraulic properties of the soil and the rooting system of the plants. From previous investigations it was known that porosity and hydraulic functions were different in tilled and untilled loess soil (Ehlers and van der Ploeg 1976). Therefore we expected that water uptake pattern of wheat roots might be influenced by tillage. The aim of the investigation was to show, from which soil layers water is extracted by wheat plants and how water extraction is influenced by rooting density, by water content and water tension respectively and by the porosity of the soil.

MATERIALS AND METHODS

The experiment was conducted in 1971 with winter wheat on tilled and untilled grey brown podzolic soil derived from loess. On untilled plots tillage had been omitted for four years. Within 2 m deep soil profiles moisture tensions were recorded daily and water contents were determined twice a week. Root weight of wheat plants was determined at seven dates during the vegetation

period. More details on soil and methods are given elsewhere (Ehlers, 1976a, 1976b).
The theory for determining water uptake by roots from distinct soil layers is presented by Ehlers (1976b). It is based on the notion that total water flux within the soil profile is composed of capillary flux and flux through plant roots. Therefore, for evaluation of the water flux through roots capillary flux has to be subtracted from total water flux (Ogata, Richards and Gardner, 1960).

RESULTS AND DISCUSSION

Total water flux (v_{total}), capillary water flux through the soil matrix (v_{cap}) and water flux through roots (v_{root}) are presented in Figure 1 (left side) for untilled and tilled soil and for two periods in July. At July 2-5 the soil was still moist because of high precipitation in June. This is indicated by the tension profile at the right side of the figure. In 40 cm depth a "water divide" may be noticed, which separates capillary flux (v_{cap}) in an upward flux due to evaporation and a downward flux due to seepage. At the soil surface the curve of v_{total} indicates that total evapotranspiration of the wheat plants amounted to 6 to 7 mm per day in both tillage treatments. Water uptake of roots was more or less restricted to the top layers of tilled and untilled soil (middle of the figure). At July 22-25 the upper part of the soil profile had lost water mainly due to evapotranspiration and the lack of rainfall (compare tensions in Figure 1). Evapotranspiration rates had decreased to about 3.5 mm per day and maximum water uptake had shifted to 30-60 cm soil depth.
In Table 1 the cumulative water uptake by the roots from different soil layers in July is compared with rooting density at July 13. Root distribution was similar in tilled and untilled soil and water was mainly absorbed from the 0-10 and 10-20 cm top layers (Taylor and Klepper 1973), where 60 to 70 % of wheat roots were concentrated. Only 15 to 17 % of the water, which was evapotranspirated by the plants, was taken directly from layers below 60 cm depth. Although rooting density was similar in the 20-30 cm layer of both tillage treatments, water uptake from the layer of tilled soil was only 50 % of the water uptake from the layer of untilled soil.

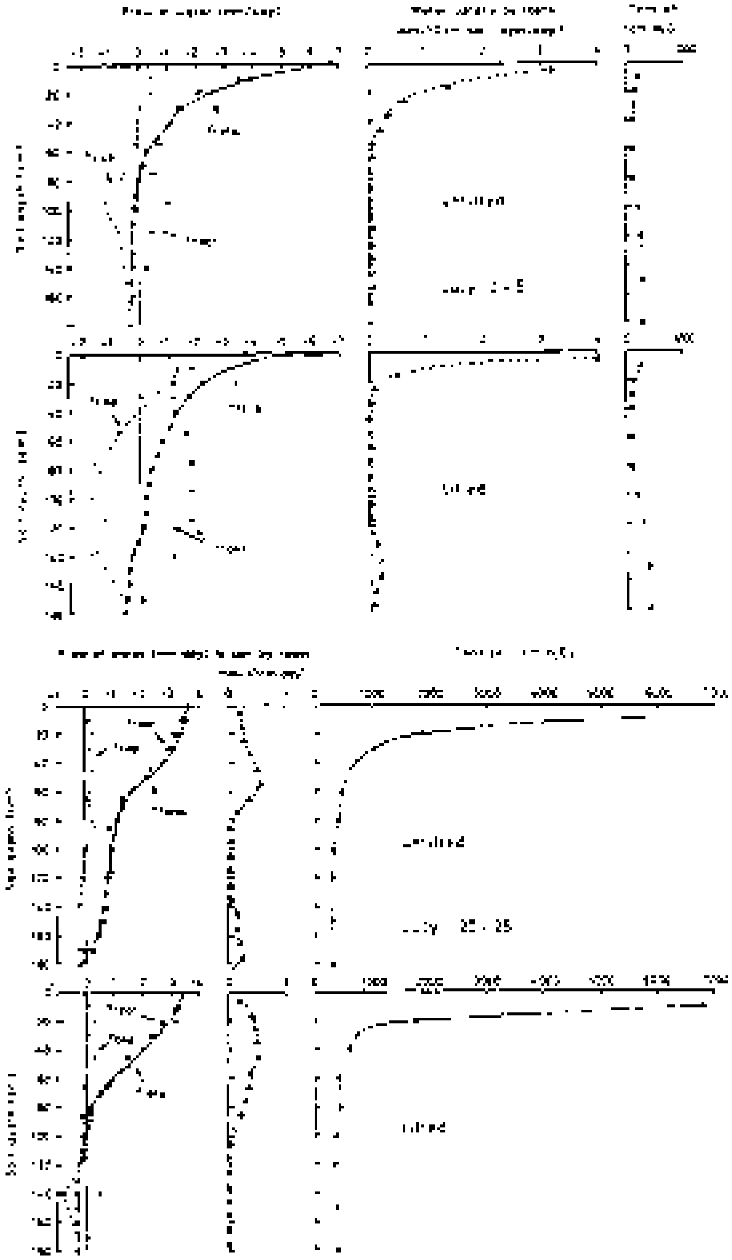

Fig. 1 - Total water flux, flux through soil and wheat roots and water uptake rates per 10 cm layer in untilled and tilled soil as influenced by soil moisture tension (2 dates).

Table 1 - Water uptake by roots of winter wheat from distinct soil layers (July 1-25) and root distribution within the profile (July 13). Tilled and untilled soil

Layer	----tilled----				---- untilled ----			
	W.uptake		Root dens.		W.uptake		Root dens.	
(cm)	(mm)	(%)	(g/m^2)	(%)	(mm)	(%)	(g/m^2)	(%)
0-200*	113	100	53	100	125	100	60	100
0- 10	40	35	28	[illegible]	35	28	29	49
10- 20	24	21	8	15	21	17	8	14
20- 30	6	5	5	9	13	10	6	9
30- 40	13	11	3	6	14	11	4	7
40- 50	7	6	3	5	14	11	4	6
50- 60	3	3	2	[illegible]	10	8	3	5
60-200*	19	17	4	7	15	15	6	10

* Roots in 0-100 cm and 60-200 cm respectively

Water uptake rates within various layers of tilled and untilled soil are presented in Figure 2 as a function of unsaturated hydraulic conductivity and related water tensions and air contents. Furthermore the influence of root density as determined at seven dates during the vegetation period on water absorption is shown in the figure. The curves were obtained by multiple regression analysis using data on water uptake rates, root weight and hydraulic conductivity. In the 0-10 cm layers of both tillage treatments uptake rates decreased sharply with decreasing conductivity and increasing tension and availability of water got reduced already at tensions less than 1 bar. In layers below 10 cm depth of tilled soil and in the 30-40 cm layer of untilled soil water absorption was small at low tensions, increased with increasing tensions and reached maximum values within the tension range of 0.5 to 1 bar. At higher tensions water absorption decreased again. Similar results were reported by Yang and de Jong (1971). The transpiration rate of wheat plants, grown in a soil column of 45 cm depth, was highest at about 1 bar tension. Reduced transpiration at lower tensions was attributed by the authors to reduced soil aeration. As aeration is a diffusion process depending on path length, it seems reasonable that in the soil layer nearest the surface water uptake decreased continually with an increase in tension.

Results presented in Table 1 and Figure 2 elucidate that water uptake may be small in that layer, which comprises the tillage depth. It seems obvious to relate the ability of roots for water uptake to the porosity and the pore size distribution of the soil. These data are listed in Table 2.

Within the tilled soil the 20-24 cm layer had the smallest porosity and air capacity, but compared to untilled soil differences were only slight. On the other hand it was shown by Ehlers and van der Ploeg (1976) that the unsaturated hydraulic conductivity in the low tension range (<0.1 bar) was less in the 20-30 cm layer of tilled soil as compared to adjacent layers and the layers of untilled soil. The same was true with the saturated hydraulic

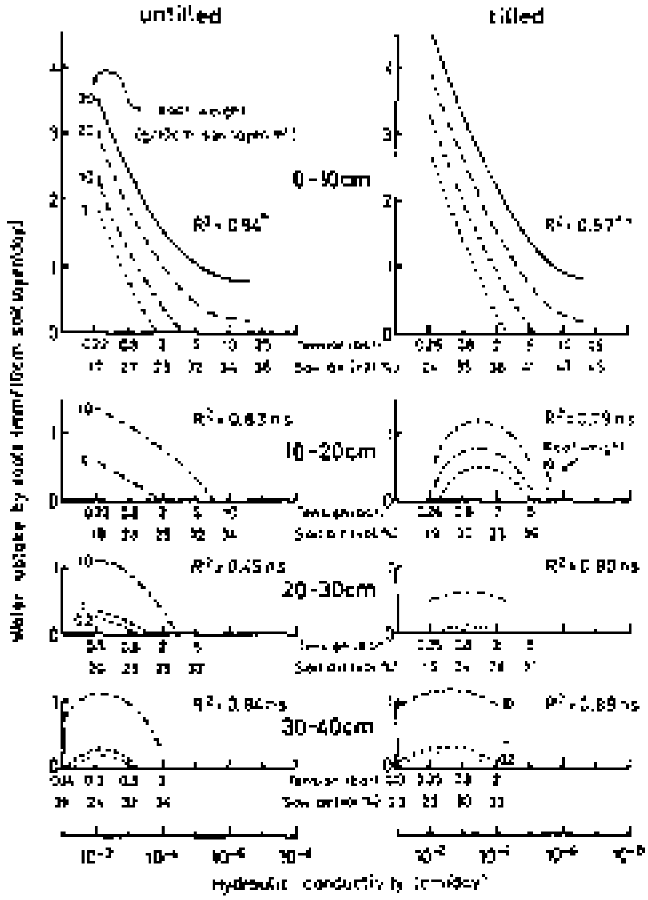

Fig. 2 - Water uptake rates of wheat roots from 10 cm layers of untilled and tilled soil as related to rooting density and unsaturated hydraulic conductivity, soil air and water tension, respectively (7 dates from April to August).

Table 2 - Porosity and volume of pore classes in various layers of tilled and untilled soil

Layer	tilled				untilled			
	Porosity	Pore class (µ) >30	3-30	< 3	Porosity	Pore class (µ) >30	3-30	< 3
(cm)	vol. %							
2- 6	52.7	18.3	10.5	23.9	44.9	7.7	10.6	26.6
10-14	48.0	12.5	8.0	27.5	45.3	9.2	9.3	26.8
20-24	44.0	7.4	8.7	27.9	44.9	8.0	10.6	26.3
30-34	47.6	11.6	11.6	24.4	48.6	13.7	11.6	23.3

conductivity (Ehlers, 1975). We supposed that regular plowing reduced the continuity of pores connecting top- and subsoil (Ehlers, 1976a). Such a kind of pore interruption was demonstrated for macrochannels built up by earthworms (Ehlers, 1975). The consequences of restricted water flow caused by tillage may be seen from water contents averaged from April to August, which are listed in Table 3 for various layers of tilled and untilled soil. Water contents were higher in tillage depth of the

Table 3 - Water contents averaged from April to August in different layers of tilled and untilled soil

Layer (cm)	tilled	untilled
	Water content (weight %)	
0-10	15.1 ±7.0*	17.2 ±6.2
10-20	17.2 ±5.8	16.3 ±4.4
20-30	17.7 ±4.1	16.6 ±4.1
30-40	17.7 ±3.2	17.3 ±3.8

* Mean ± standard deviation

tilled plot as compared to the untilled plot and limited water flow caused the higher variation of water contents in the top layers of the tilled soil (Ehlers, 1976a). We believe that limited water uptake by roots in the 20-30 cm layer of tilled soil was caused by the structure of that layer. The slightly reduced porosity in connection with the pore discontinuity might have caused aeration deficiency on a micro-scale due to higher water contents. It seems to us that for the first time water uptake of roots was shown to be influenced by a plow sole, even though it was only as slightly manifested as in this experiment.

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REDUCED TILLAGE SYSTEMS FOR THE SEMIARID WORLD

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ABSTRACT: Reduced tillage can be beneficial to the semiarid regions where rainfall, wind, storm intensity and soil is highly variable. A reduced tillage system uses tillage to control weeds, conserve moisture, prepare the seedbed for rapid germination and development of the crop while protecting the soil from erosion. Fewer trips across the field means reduced energy, time and labor inputs with minimal reduction of vegetative residues and minimal soil compaction. Reducing tillage operations also usually results in less runoff and evaporation which means more water for crop production.

DISCUSSION: More than 50 percent of the earth's land surface is considered to be in regions where annual precipitation is less than 50 cm. In these regions, water is the major factor limiting crop production because rainfall is low in comparison to crop water demand. Dryland farming is the term generally applied to arable agriculture where irrigation water is not provided. A suitable system of land use management must enable production and provide means of controlling water and wind erosion at an acceptable level. In many semiarid and arid regions, local topography is the result primarily of wind action. Windblown soils are commonly coarse textured and are very susceptible to erosion. Management directed at erosion control and moisture conservation is particularly important in these areas. In the semiarid and arid regions, the proportion of time devoted to cropping should be related to amount, effectiveness and reliability of moisture. Cultivation should be minimal and directed toward moisture and soil conservation and providing suitable conditions for seeding, germination and crop development. Developing satisfactory land use management practices is complicated by variations in climate and soils. Rainfall is variable within and between years and varies within small areas. Physical and chemical soil properties may also vary considerably in a relative small area. Land use management practices must stabilize crop production and soil erosion. A sound management system should have a stabilizing influence from year to year in spite of the variation in climatic and soil factors. Cropping practices may not take full advantage of favorable conditions but are necessary to adequately safeguard production during unfavorable conditions.

The primary purpose of tillage is to control weeds, reduce wind and water erosion, increase moisture storage and nutrient release through fallow, and prepare a firm mellow seedbed. The energy requirement for plowing is high in relation to other methods of initial tillage. Each time a tillage operation is performed, moist soil is exposed and soil moisture is lost by evaporation. This soil moisture loss reduces the value of fallow. Reduction in surface vegetative cover leaves the soil more subject to wind and water erosion and lowers the infiltration rate. As wind erosion increases, pollution of the air by dust increases. As water erosion increases, the chances of sedimentation in lakes and streams increases.

A reduced tillage system uses tillage for the primary purpose of controlling weeds, conserving water and preparing the seedbed for rapid germination while protecting the soil from erosion. Underground cutting tillage tools that do not expose moist soil may be used for weed control. Herbicides may be used for replacing all or part of the tillage operations. Weeds must be controlled in all phases of crop production to prevent further development of a source of weed seed. Several operations may be combined into one operation to eliminate traffic over the soil. Many terms are used for reduced tillage systems. They include conservation tillage, minimum tillage, zero tillage, ecofallow, stubble mulch tillage, chemical fallow, till plant, stale seedbed, and planting, disk and plant, chisel and plant, lister planting and slot planting--all of which involves reduced tillage.

Every system of tillage involves specific problems. Reduced tillage allows more residues to be produced and accumulate on the soil surface. Although residues are beneficial, the maintenance of residues on the soil surface develops a physical problem effecting machine operations, especially planting. Tillage and seeding machines must have ample clearance to prevent clogging with residues. They must also develop sufficient agitation of the soil to control weeds while leaving a mulch on the soil surface. Placing seed firmly into moist soil without leaving residues over the row is frequently a problem with present planting equipment, especially with small grains. Residues lower soil temperatures because of their insulating effect, increases reflection of radiant energy and reduction of surface evaporation (6). A wetter zone near the surface is usually encountered with residues on the soil surface. In medium to fine textured soils, the wetter condition makes weed control more difficult. However, under dry conditions, especially on the coarser textured soils, the wetter condition near the surface will be beneficial for planting and stand establishment.

There is much evidence indicating that undisturbed soil is a satisfactory rooting zone. Root action, freezing and thawing, wetting and drying, tend to maintain favorable physical soil conditions. Compaction caused by tillage implements constantly present problems in maintaining good soil physical condition.

The requirements for effective conservation systems are evident from the principles of the wind erosion equation developed by Chepil and Woodruff (9). Vegetative residues on the land surface and a rough and cloddy soil surface reduce wind erosion. Field widths along the prevailing wind direction need to be as short as possible and still permit reasonable efficient farming operations with machinery. The specific requirement for residue, cloddiness, roughness and field width vary depending not only on the influence of these variables on each other and their practicality, but also on the additional variable, climate.

Woodruff and associates (8) have shown that the quantity, size, and orientation of vegetative residue covering the soil surface influence the degree of wind erosion control. On an equal-weight basis, standing residues are more effective for wind erosion control than residues lying flat. As a general rule, to hold wind erosion to a tolerable level of 10 metric tons/ha, about twice as much flattened residue is needed compared with standing residues. Fine-textured residues produced by small grains are more effective than coarse residues produced by sorghum (8). Coarse-textured soils require more residue for soil protection than fine-textured soils. Approximately 1050 kg/ha of wheat residue is required to protect a silty soil and 2400 kg/ha for a loamy fine sand soil.

TILLAGE IMPLEMENTS: Tillage machines used for stubble mulching are of two types (1,2,3): (1) Those that stir and mix the soil including disks (oneway disk, offset disk and tandem disk), chisel plows and mulch treaders and (2) Those that cut beneath the surface without inverting the tilled layers including sweep plows, rodweeders with semi-chisels and rotary rodweeders.

STIRRING AND MIXING IMPLEMENTS:

Disk-type Implements: Disk-type implements have a gang of disk blades 40 to 65 cm in diameter, spaced 20 to 25 cm apart. They are operated at an angle to the direction of travel to give a cutting and turning action of the soil. The disk-type implement will bury from 30 to 70 percent of the residue on each trip across the field, depending on the disk type and how it is operated. Increasing size, concavity and spacing of disks and depth of operation all increase the amount of residue buried on each operation. The disk-type implements give good control of weeds. They also can be used to reduce extremely heavy residues when necessary.

Chisel Plows: Chisel plows are heavy tool carriers with high clearance shanks spaced 30 cm apart, equipped with 5 cm chisels or up to 46 cm shovel sweeps. The purpose of the chisel plow is to kill weeds by partially inverting the soil and severing the weed roots. Chisel plows also loosen the soil and leave the surface rough with residues for erosion control. The percentage of residue retained on the soil surface with the chisel generally decreases with increased amount of residues but increases with greater height of stubble. For more effective weed control, a rotary rod can be used behind the last row of shanks. The rod can be ground, hydraulic or power take-off driven.

Mulch Treaders: Mulch treaders are a gang of wheels with curved teeth or curved chisels protruding. The wheels are 40 to 50 cm in diameter, spaced 20 to 25 cm apart. They can be operated in tandem and at a slight angle to the direction of travel. Mulch treaders are used as secondary tillage tool to improve weed control, especially when shallow-rooted weeds are present.

SUBSURFACE IMPLEMENTS:

Sweep Plows: Sweep plows are usually equipped with 75 cm or larger sweeps. Large sweeps are often referred to as a V-blade. Sweeps range from 150 to 180 cm in width. The blade width of the sweep ranges from 15 to 30 cm with about a 37-degree pitch for soil lift. The angle of a V-blade ranges from 60 to 100 degrees. The wide angle sweep penetrates the soil better, but shedding of weed roots and residues is frequently a problem necessitating less angle. The sweeps are mounted on a heavy tool carrier with standards having at least 75 cm clearance between the bottom of the blade and frame of machine for residue clearance. If widths of more than 360 cm are needed, they are frequently designed to have each sweep flexible from the others for uniform tillage. To prevent clogging of standards in heavy residues, rolling coulters of at least 50 cm in diameter are a necessity. The major disadvantage of the underground tillage tools is lack of weed control, especially when grassy weeds are present under moist conditions. V-sweep plows can be used for most of the tillage operations during fallow. Usually the last tillage operation prior to seeding is done with a rotary rodweeder.

Rodweeder: The rotary rodweeder is a machine equipped with a rod

2.5 cm square that operates under the surface of the ground. The usual depth of operation is 5 to 7 cm below the soil surface. The rod rotates backwards to the direction of travel for trash clearance. A shank holds the rod in the ground. The rod is driven either with a ground wheel, power take off or hydraulic motor. It is an excellent secondary tillage tool to firm the soil and control small weeds, especially prior to seeding the crop. Rodweeders reduce the residue 5 to 10 percent for each tillage operation. Rodweeders can be equipped with a row of semi-chisels mounted directly above the rod. The semi-chisels are designed to penetrate firm ground.

SELECTING TILLAGE TOOLS: (3, 7) No one set of tillage tools is best for all conditions. The kind, quantity and quality of residues, number, kind and size of weeds present, moisture conditions, soil texture, length of fallow and time of operation should be considered when selecting tillage tools. Speed and depth of operation, width of equipment, concavity of disks and width, pitch and angle sweep blades are all factors in residue retention and weed control. Height and length of stubble and positioning or orientation of residue also influence the amount of residue buried.

TILLAGE SEQUENCE: Combinations of sweeps, disks, and rodweeders will be needed for particular situations. Choice of machines and sequencing is based on the amount of plant residue present at the beginning of fallow, the amount of residue needed at seeding time, and the weed situation. If residues after harvest are light (less than 2,300 kg/ha) sweep machines or rodweeders with semi-chisels should be used for all tillage operations except the last one, which should be done with plain rotary rodweeder. If the residues are medium (2,300 to 4,600 kg/ha), the oneway, tandem or offset disks can be used as a first operation, followed by subsurface tillage equipment such as a sweep, or a rodweeder with semi-chisels. The last operations should be with a plain rotary rodweeder for seedbed firming and weed control. If residues are extremely heavy (4,600 to 6,800 kg/ha), the disk-type implements are best used for several operations, followed by chisel or sweep and finally, the rodweeder. Disk-type equipment has an advantage in a wet spring, when grassy weeds such as downy brome (*Bromus tectorum* L.) and volunteer wheat are a problem.

Maximum moisture storage efficiency and residue maintenance should always be considered when contemplating a tillage operation. Weeds must be controlled to conserve moisture. Tillage is advisable when weeds are consuming more moisture from the soil than would be lost with a tillage operation. If there are only a few weeds in the stubble at wheat harvest, the stubble is usually left until spring. If weeds are present in sufficient quantity to utilize moisture or will set seed, tillage should be performed soon after harvest. The annual bromegrasses such as downy brome in the spring of the year must be controlled before they set seed. Soil must be in a tillable condition to control weeds. Poor weed control will result and tillage layers may develop in the soil if tilled when too wet. The same general tillage tools described for fallow can be used for seedbed preparation for continuous cropping. Prior to planting, a firm mellow seedbed needs to be developed that is weed free and has sufficient moisture to germinate the crop.

ECOFALLOW (CHEMICAL FALLOW): (4) Ecofallow is a system of controlling weeds and conserving soil moisture in a crop rotation with a minimum disturbance of crop residue and soil. Weed control is obtained with herbicides or the combination of herbicides and subsurface tillage operations on fallow land. Each time a tillage operation is performed, moisture is lost due to the tillage action on the soil. Protective cover of residues on the land for soil protection is easier to maintain with no tillage or limited tillage operations. Each time the land is crossed with equipment, residues are flattened or incorporated into the soil.

Certain problem weeds such as downy brome and volunteer wheat would be easier to control with correct herbicides. Downy brome and volunteer wheat begin growth late in the fall or early spring and downy brome sets seed during the first part of May. When the spring season is late or wet, it is difficult to control grass weeds before they set seed, especially with stubble-mulch tillage equipment. Reducing the number of tillage operations not only reduces energy requirements but may also improve the physical condition of the soil.

Recent studies indicate that where adequate weed control is obtained with herbicides, moisture conservation and crop yields are as good or better than conventional fallow methods.

The success of ecofallow will depend upon the development of a herbicide which will work under variable climatic conditions. The herbicide will need to be effective for a definite period of time, then break down rapidly so as not to interfere with future crop production. A preemergence herbicide that will remain active for 3 to 4 months, then disintegrate rapidly, will be satisfactory for spring application on fallow land. Herbicides which remain effective for more than four months, but not to exceed 10 months, would be desirable for fall application on fallow land. Preemergence herbicides will also need to have sufficient latitude to allow for error in application, overlapping of material during application and suitable over a wide range of soil types. An economical contact herbicide that would replace a tillage operation or could be used to kill existing weeds at time of application of a preemergence herbicide is needed. The herbicides must control a wide range of grass and broadleaf weeds without injury to the crop. Ecofallow is in the experimental stage and not widely used. Further development will fulfill many of the objectives of stubble-mulch fallow.

SEEDING EQUIPMENT: Proper seeding equipment is essential for planting in residues. Seed must be placed firmly in moist soil with 2 to 5 cm of soil cover and with adequate protection from wind erosion. Seeding equipment should preserve as much residue as possible and securely anchor the residues in the ridges, leaving a rough, cloddy surface. Deep-furrow drills, equipped with hoe or shoe openers, are the most satisfactory drills for seeding close sown crops in soil with moderate amount of residue on the soil surface (3,400 kg/ha or less). Seeding in the soil under heavy residues, with and without tillage, requires planters which will place the seed into moist soil without clogging or placing residues over the newly seeded crop. To seed in heavy residues, with or without tillage, requires cutting through the residues. The seeding equipment must have sufficient clearance between the openers, press wheels, and rolling coulters to prevent clogging and bunching of residues. Residues must be cut cleanly to prevent clogging and to leave an area over the newly seeded row free of residues. Seed must be placed firmly into moist soil for rapid germination and seedling development.

SUMMARY: Reduced tillage has the greatest potential benefits in the semiarid regions where rainfall, wind, intensity of storms and soil are highly variable. Crops grown in semiarid regions without supplemental water are usually low value crops. Fewer trips across the field means reduced energy, time and labor inputs--all of which adds to the cost of production. Reduced tillage operations due to less tillage action or fewer trips across the field will result in less reduction of vegetative residues and soil compaction. Good soil structure and vegetative residues are important to reduce runoff and sedimentation from crop land--also a greater reduction in wind erosion which means soil loss and air pollution. Frequently tillage practices are needed on bare fields to break the surface crust to control wind erosion. Effective use of herbicides could result in reduced tillage and losses due to weeds. Reducing tillage operations usually result in less runoff and less evaporation which means more water in the soil profile for crop production. Reducing tillage operations, storing more soil water and reducing erosion will result in higher yields and lower unit cost of production.

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IDENTIFICATION OF SOILS SUITABLE FOR DIRECT DRILLING

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ABSTRACT

The effect of soil structure on direct drilled crops in the U.K was surveyed in 150 fields over a two year period. Successfully direct drilled soils had many large pores (> 100u diameter). Low porosity in soil surfaces was produced by smearing, slaking, compaction and trash, this caused poor germination and emergence. Overcompaction lower down in the soil profile caused drainage and/or rooting problems. Many soil types under continuous direct drilling maintained adequate porosity for at least 5-10 years. Increasing the direct drilled acreage will involve teaching farmers to carry out visual assessments of soil porosity and to correct any soil problems before direct drilling.

INTRODUCTION

The success of crops sown by direct drilling (zero tillage) depends on the physical conditions of the soil. During the last ten years ICI has developed guidelines on the physical conditions required for satisfactory direct drilled crops (1). These are used by farmers and contractors; thus they have been based on visual assessment of soil structure plus a knowledge of its drainage characteristics. Detailed measurements of a wide range of physical properties can aid our understanding of the relationship between crop yield and soil physical properties. However, they are too slow (soil physical properties can change rapidly in the field) and expensive for general use by farmers who have to make an 'on the spot' decision as to the suitability of soils for direct drilling.

This paper discusses the results obtained from a survey of the relationship between soil structure and crop success in 150 direct drilled fields. It also discusses the advantages and disadvantages of continuous direct drilling on different textured soils.

Sites and Crops Studied

Between December 1973 and May 1975, 153 direct drilled fields were visited at 76 different sites. Their distribution was representative of the direct drilling acreage in England and Wales. On 20 sites a ploughed comparison was looked at which was either part of or adjacent to the direct drilled field. Fifteen sites were yield trials and 11 had at least two replicates of each treatment. The crops being grown are shown below; a high proportion of fields were direct drilled small grain cereals (45%) and/or winter crops (54%)

TABLE 1 Crops being grown on assessed soils. (Total of 153 fields)

Crop	No. of fields visited	% of total
winter wheat	52	34
winter barley	12	8
spring wheat	12	8
spring barley	23	15
winter oats	5	3
winter oilseed rape	13	8·5
forage main crops maize, kale, turnips	17	11
not yet drilled	19	12·5

Soils were classified by hand-texturing and by mechanical analysis using the system in the booklet 'Cereals without ploughing' (2). About 43% of soils were Heavy soils - Group 1; 26% were Medium soils - Group 2; and 31% were Light soils - Group 3. About 30% of fields were in the 'winter crops on heavy land' category.

Weather Conditions

Weather conditions during the two seasons were extremely contrasting. Autumn 1973 was the fourth dry one in a row; Spring 1974 was drier and colder than average; Autumn 1974 was abnormally wet creating problems for autumn cultivation; Spring 1975 was also very wet and late.

Methods of soil structure assessment

The top 20-25cm of soil in all fields was examined with a spade as described by Peerlkamp (3) but without any structural 'scoring'. Soil was brought to the surface and each spit was assessed for overall structure and porosity. Aggregates were then separated by hand and examined for pores greater than 100μ diameter which are just visible to the naked eye. About five or six spitfuls of soil were taken at random from each field and where variations in crop growth existed, samples of these were compared simultaneously. Excessively compacted soils from headlands and gateways were also examined. All soil spits were photographed, hand textured, and samples taken for laboratory analysis. An auger was used to sample subsoils for texture determination but in cases where a reason for poor crop growth was not found in the surface a deeper soil pit was dug. The soil profile was considered in two parts; firstly, the surface 5cm of soil which affects the drilling operation, germination, and early growth and secondly, the soil conditions deeper in the soil profile.

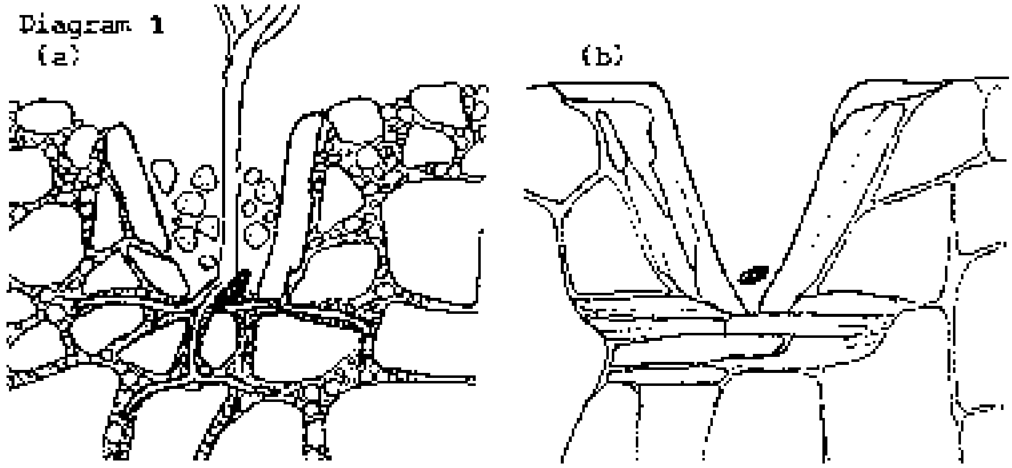
1. CONDITIONS IN THE SOIL SURFACE

The first objective with direct drilling is correct seed placement and good contact with firm but porous soil. Surfaces with good crumb structures are ideal because as the tine or disc runs through the surface, soil can flow back over the seed. Such a condition is generated in most seasons by frosts and wetting/drying cycles.

Less than ideal drilling conditions were caused by the soil being too wet or too compacted in the surface; use of the Bettinson 3-D triple disc drill here resulted in an open slot. In wet conditions the slot was open because of smearing by the rear double discs. In some cases this had no effect on the crop as in Diag.1(a) where soil immediately below the slot is reasonably porous. Here chain harrowing behind

Diagram 1

(a) (b)



the drill to break up slots and drag soil over the seeds was very effective. In a severely smeared slot (Diag.1(b) such as was often seen on heavy soil types during the wet autumn of 1974, the effect on emergence was severe. Seminal root growth into the lower soil was restricted by the smeared slot bottom and drainage out of the slot was slow. On soils which were wet and compacted in the surface water sometimes drained from areas between the slots into the slots themselves. The significance of a loose surface 2cm of soil lay in its ability to assist the drainage of excess water from the immediate vicinity of the seed. Even soils with some subsurface compaction maintained a good stand of winter wheat over the exceptionally wet 74/75 winter provided this loose surface layer was present. This has increased the interest in tine-based direct drills which create more surface disturbance and may give better results with winter wheat in a wet season. Tolerance to smeared slots also varied with crop; wheat was reasonably tolerant while oilseed rape was adversely affected more often.

Slaking, the collapse of soil structure due to the impact of heavy rain was not a problem which affected direct drilled crops presumably because of soil stabilisation by the previous crop. Crop failure partially due to slaking was seen on only two unstable soils; this was accentuated by surface and subsurface compaction. As with smearing, slaking cut down the porosity of the soil around the seed and hence poor drainage became a problem. In no case did slaking and consequent surface 'capping' alone prevent seedling emergence.

Excessive trash on the soil surface sometimes caused disappointing results with direct drilling in the UK. This is due to pests such as slugs, and also to toxic extracts from straw. Another cause is the mulching effect of trash which prevents weathering of the soil surface and development of a good crumb structure. It was noticed that when farmers were waiting for the soil to dry out before drilling, the soil beneath 'laid' straw and even between long standing straw was less friable, wetter and more plastic than soil in trash-free areas.

Many soil surfaces can be easily ameliorated to give improved results with direct drilling. For example rolling after spring and summer drilling of kale, swedes, and turnips can have a beneficial effect on emergence. Not only will this close the slot and prevent moisture loss, but it also fills slots with crumbs and granules. Another widely and successfully used implement is the chain harrow which minimises surface disturbance but increases the coverage of the seed with soil. In marginal soil conditions, for example when the top 5cm of soil have been compacted by harvesting, it may be preferable to use a straight-tine harrow, or a spring-tine cultivator to disturb soil to this depth to artificially provide a suitable surface. Straight tines have been used successfully before spring barley on heavy soils where it was necessary to provide soil crumbs on the surface but to leave larger aggregates buried. Spring tine cultivators which have the opposite effect may however be preferable on more unstable soils where slaking could occur if the surface aggregates were too fine. Some direct drills used in the UK, in particular the International 511 drill, have spring-tines as soil openers.

2. CONDITIONS IN THE SOIL PROFILE

It was found that although farmers and contractors recognised the surface conditions best suited to direct drilling and the need for harrowing or rolling, they paid less heed to underlying soil conditions, such as compaction. Typical symptoms of compaction were bad drainage or crops which emerged satisfactorily but later declined in vigour. Layers of compacted soil in the profile restricted drainage and root growth because of the scarcity of large pores. Winter crops died back through waterlogging, and spring and summer drilled crops failed to put down enough roots to the subsoil to ensure adequate water supply. Plant roots responded to overcompaction by becoming generally thickened and stunted with extensive lateral root growth.

Good natural or artificial drainage indicates that a soil has enough large pores for adequate root growth. One exception, however, is coarse sandy soil types with low organic matter. These soils are unstable and tend to 'close pack'. When this occurs the remaining pores are still large enough for free drainage; 60μ diameter is the approximate limit for the movement of water under gravity (4). However these pores are too small for growth of cereal roots (5). Hence seedlings from direct drilled spring cereals, which have limited penetrating power, are unable to push their way through a soil which is drying and hardening. Winter cereals establishing when the soil is moister and softer have been much more successful on these soils.

Other unstable soils such as fine sands and silts may be affected by natural settling over the winter period giving rise to a massive condition. Yields may be affected in the first year of direct drilling and more so in the second.

Remedies for more deep-seated soil problems which should be carried out before direct drilling should be based on the rule 'Do no more cultivation than is necessary'. As with ploughing, moledrainers and subsoilers can be used to rectify soil problems. The indication is that the need for these may decrease with continuous direct drilling once the problems created by the plough have been overcome. Excessive loosening of the soil by cultivators before direct drilling is undesirable. If the natural structure of the soil can be retained, as with moling or subsoiling, then the inherent strength of the soil makes it less likely to compact under the drill, fertilizer, or herbicide applications or harvesting. Soil disturbance is excessive when chisel tines or heavy flexitines are used and should be avoided except in severely compacted soil. The problem of how to achieve a good shatter in the 0-20cm horizon where compaction can occur under direct drilling, yet leave an even surface is of great current interest. If this can be achieved many potential acres on poorly structured soils would be open to continuous direct drilling with possible benefits in soil structure improvement.

CHANGES IN SOIL STRUCTURE UNDER CONTINUOUS DIRECT DRILLING

Three characteristics existed in soils which had been direct drilled for up to ten years. These were; a gradation in colour down the profile, the darkest soil being on top; an active earthworm population; and a modified soil structure. The colour changes were due to differences in soil organic matter added to the surface in the form of plant debris and ash from burning.

TABLE 2. Percentage organic matter profiles in a range of soils.

Soil texture	Calcareous loamy sand	Calcareous clay loam	Loam	Silty clay loam
No of years direct drilled	10 cereals	10 cereals	6, kale, barley, grass rotation	3 cereals
0–2·5 cm	4·6	2·8	6·7	2·7
2·5–5 cm	4·1	2·5	6·5	2·4
5–10 cm	3·7	2·3	5·1	2·7
10–15 cm	3·7	2·2	4·4	2·1
15–20 cm	3·4	2·3	3·5	

This colour effect was not pronounced in very dark chalky organic soils or on some heavy soils with only two or three years of direct drilling. It has been reported that profiles of soil organic matter can be reflected in aggregate stability by wet sieving (7). During this investigation such a correlation has not generally been found.

In direct drilled soils the earthworm population appeared to be high; up to five times the number in cultivated plots on the same soil have been reported (8). Their activity was responsible for much of the large pore space with burrows up to 5 mm in diameter. These were darkened suggesting that earthworms were also redistributing organic matter in the soil. Earthworm channels contributed to drainage of direct drilled soils and some farmers claimed that previously waterlogged fields have been drained by this feature. Other benefits have been the use of burrows as root channels and improvement of surface tilth by casting species.

The changes in structure associated with long term direct drilling were more evident on clay soils than lighter limestone, chalky or organic types. Clay soils tended to develop an apparently 'massive' structure, that is, the soil profile was uniform with few individual soil aggregates; these fitted together tightly with little loose soil between them. That is, below about 3 cm the structure possessed many of the attributes of clay subsoils. However, a closer inspection often revealed that the 3–20 cm soil layer, though apparently massive, was really very porous. The extent of the complex interconnecting pore system of earthworm burrows, old root channels, fissures and cracks could only be seen by breaking the soil open by hand. As well as being porous such soils were also mechanically strong. The surface 2–3 cm of soil usually had a stable crumb or granular structure, ideal for further direct drilling. This type of modified soil structure was common on heavy clays, silty clay loams after about three years direct drilling, it was particularly characteristic of calcareous heavy soils such as chalky boulder clays. It was also evident on lighter soils with reasonable organic matter levels (> 2%) such as Old Red Sandstone, East Anglian 'skirt' soils and some loams. Other soils which were poorly structured for example coarse sands, fine sands and silts often gave poorer results in the second year of direct drilling and were ploughed up. Because of this the long term effects of direct drilling could not be evaluated on soils which did not have an initially porous structure.

In the long term success with direct drilling depends on factors such as soil strength, stability of aggregates in wet weather, cracking in the summer and frost heave in the winter, and also on biological factors such as good root growth and an active earthworm population. These factors are vital if enough large pores are to be maintained when the soil is subject to compaction during grazing, harvesting, and settling under gravity. Visual assessments of soil structure are more significant than physical measurements when considering soils for direct drilling. It is of prime importance for farmers to acquaint themselves with the structure and properties of soils and to think more closely about the way that direct drilling and minimum cultivation techniques can be used advantageously.

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DANISH EXPERIMENTS ON REDUCED TILLAGE

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ABSTRACT

The climate in Denmark is humid, and the soil types are sand or sandy loam. About 5o per cent of the total agricultural land is grown with spring sown barley. Tillage experiments show, that it in several cases is possible to reduce the numbers of operations in autumn and spring.

Field experiments with rotavating and harrowing to a maximum depth of 1o cm have given a reduction in yield of 1.6-2.3 hkg barley per hectare compared with ploughing to 2o cm depth on sandy loam. In resently started experiments the problem with ploughless farming is combinated with mulching of straw and use of green manure.

INTRODUCTION

Soil tillage is mainly based on traditions and experiences by the farmers, and tillage systems are difficult to change. Soil tillages have to be adjusted to the climate, the soil type and the crop. About 5o per cent of the soils in Denmark are sandy soils and 5o per cent are morain sandy loam.

The climate is temperated and humid. The mean annual temperature is 7.8° C, the mean annual precipitation is 682 mm and the actual evapotranspiration is 4oo mm in the period April-November. The sowing normally is carried out in April, and the growing season is about 6 months, May-November. In some years the precipitation in the growing season is insufficient for optimal plant growth. In the months December-March the soil is frozen for periods, and the precipitation falls as snow. In spring the soil normally is saturated to field capacity.

A crop rotation with grain, grass and fodder beets in former times was usual in connection with mixed farming with cattle and pigs. The growing of spring sown barley has rapidly increased, and 1.4 mio. hectare or 5o per cent of the total agricultural land in Denmark in 1975 are grown with spring sown barley.

One of the main problems of soil tillage in Denmark is how to grow barley.

PURPOSE

In soil tillage we have in view:
1. to make weed control and to mulch the stubble
2. to change and to improve the soil structure and to make a good seedbed for germination of the grain.

In Danish farming the interest for reduced tillage is increased. One reason is to reduce the costs in plant growing, and a second reason is to get a better soil structure and preserve the organic matter. The requirement is, that crop yield must not decrease, and the variation in the yield from year to year must be small.

Reducing the tillage may take place in two ways:
1. Reducing the numbers of operations.
2. Tilling to a lesser depth.

TRADITIONEL SOIL TILLAGE IN DANISH AGRICULTURE

Stubble treatments normally are carried out with shallow ploughing or harrowing to 10-15 cm depth after harvest in August. Harrowings are repeated 2-3 times in the autumn. The purpose is weedcontrol, mainly coach grass and mixing the stubble.

In October-November nearly all areas are ploughed by means of mouldboard plough to 20-25 cm depth. Seedbed preparation is carried out in April by harrowing 2-4 times to a depth of 5-10 cm. Sowing is carried out by drillmachine. By experiences the farmers know how to use the different implements, and under which conditions they can be used.

Changes to other systems or new implements rize problems to give the right instructions in the use.

EXPERIMENTS ON REDUCED NUMBERS OF OPERATIONS

In field experiments on different farms stubble treatments have been compared with plots without stubble treatments. The soil is ploughed in October-November. Some results are shown in table 1 and 2.

Table 1 Stubble treatment (32 exp.)

	Yield hkg barley per hectare	Caracter (0-10) for coach grass	per cent ophiobolus graminis
Untreated	38.7	4.3	8
Stubble treatment	39.8	2.5	9

Table 2 Coach grass control (59 exp.)

	Yield hkg barley per hectare	Yield Relative	Coach grass shoots per m^2
Untreated	32.5	100	119
Stubble treatment	37.9	116	43
Chemical	39.6	121	30

The conclusion of these experiments is, that stubble treatment is unnecessary except on areas with coach grass. On many areas the expenses for stubble treatment can't be saved.

In table 3 the results of experiments with seedbed preparation for barley are shown.

Table 3 Seedbedpreparation

	Yield hkg per hectare	Yield Relative	Depth of treat-ments, cm	Porosity per cent
	Sandy soil (12 exp.)			
2 shallow harrowings	36.4	100	4.7	49
2 deep -	35.0	96	9.5	51
2 deep + 2 shallow -	36.5	100	6.8	50
	Sandy loam soil (19 exp.)			
3 shallow harrowings	45.6	100	5.5	46
3 deep -	45.1	99	13.3	52
3 deep + 3 shallow -	45.2	99	8.6	49

Seedbedpreparation by 2-3 times of harrowing to 4-6 cm depth has given the highest yield and the best result. Several times of harrowing and harrowing to greater depths have no effect and is unnecessary.

PLOUGHLESS GROWING OF BARLEY

Reduced depth of tilling is not possible by use of the plough. It requires new types of implements and new experiences how to use them. In Danish experiments the rotavator is used. In table 4 the traditionel tillage with ploughing to 2o cm is compared with rotavating to 1o cm depth. On an average of 3 years the ploughless treatment has given a reduction in yield of 16oo kg barley grain per hectare.

Table 4 Ploughing and rotavating (2o exp.)

	Yield hkg barley per hectare	Yield Relative
Stubble treatment, ploughing 2o cm, Seedbedpreparation	38.o	1oo
Rotavator 3 times, max. 1o cm	36.4	96

Experiments with ploughless farming have to run for a period of several years in order to measure the effect and variation in yield and change in soil structure.

In 1968 experiments on 3 soil types were started. The tillage operations and some of the results are shown in table 5.

Table 5 Barley growing without ploughing since 1968

	Yield, hkg per hectare			Relative			Pores > 3o µm		
	Sand	Sandy loam	Silty loam	Sand	Sandy loam	Silty loam	Sand	Sandy loam	Silty loam
Stubble treatment, ploughing, 2o cm, seedbedpreparation	33.5	42.3	44.7	1oo	1oo	1oo	3o.3	6.3	15.1
Chemical weedcontrol, Rotavating in spring, 3 cm	3o.6	36.9	42.4	91	86	95	3o.1	7.8	14.6
Rotavating in spring, 1o cm	34.1	41.2	41.8	1o2	93	94	39.6	19.4	28.2
Stubble treatment, seedbedpreparation, 1o cm	33.9	38.9	42.9	1o1	92	96	33.7	12.1	16.5

In the plots without ploughing there have been problems with coach grass and with lack of experiences for the right time and the right way to use the implements. In plot no. 2 it has been difficult to drill the barley seed.

On the sandy soil the ploughless tillage has given the same yield as traditionel treatment. On the sandy loam and the silty loam the highest yield is obtained after ploughing to 2o cm depth. Reduced depth of tilling has given a reduction on 1.1 - 3.9 hkg grain per hectare. The volume of large pores (> 3o μm) is higher after the ploughless tillage.

New series and experiments have been started during the last two years. In these experiments the problems of straw mulching and green manure are included in combination with ploughing and ploughless tillage.

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Comparison of implements for secondary cultivation

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Abstract

Secondary cultivation can be accomplished with implements differing greatly in principal design. In this paper the power transfer, the mixing effect, and the soil relief left by several implements will be dealt with.

The power transfer

The power for soil cultivation can be transferred from the tractor to the implement by means of pulling or via the power take off (PTO). The power transfer by means of pulling causes slippage of the tractor tires and thus a loss of power and time. Consequently, tools driven by the power take off have been developed, e.g. the reciprocating harrow, the reciprocating stars, the rotary harrow operating horizontally and the rotary harrow operating vertically. The percentage, to which the total power for these implements is supplied by the power take off, differs (Fig.1). The percentage of the power transferred to the implement by the power take off increases in the following order: reciprocating harrow, reciprocating stars, rotary harrow operating horizontally, and rotary harrow operating vertically. The reciprocating harrow still gets 32 to 46 percent of its power transferred by the tractor tires. On the other hand, the rotary harrow operating vertically did not need any power transferred by the tractor tires when the speed exceeded 2,6 km/h. Under these circumstances the power transfer to the rotary harrow operating vertically by means of the power take off was higher than the total power needed for the implement, which means that the implement is pushing the tractor.

The power transfer to the implement via the power take off should be uniform. High torque variations during the power transfer can result in vibrations of the implement as well as the tractor and can accelerate the wear. The torque variations at the power take off increased in the order rotary harrow (both types about same rank), reciprocating stars, reciprocating harrow (Fig. 2).

<u>The mixing effect</u>

A high mixing effect of cultivation implements is desirable when crop residues or fertilizer must be incorporated into soil. Generally the mixing effect is defined as the ability to distribute particles lying on the soil surface uniformly within the working depth of the implement. This definition probably corresponds to agronomic requirements. However, this definition does not take into consideration the physical factors causing the incorporation of particles into the soil (3).

The mixing effect was determined by means of maize kernels, which were spread over the soil surface. The distribution of the kernels in the soil within the working depth of the implement was measured by using a soil slicing unit according to Breitfuss (1). The mean kernel depth $\bar{x}$ as well as the standard deviation s of the kernel depth were determined.

The evaluation of the results gave similarly directed tendencies for the mean depth $\bar{x}$ as well as the standard deviation s, however, the differences between the implements in the mean kernel depth $\bar{x}$ exceeded those in the standard deviation s. The Table 1 contains the rank of the implements according to the mean kernel depth $\bar{x}$, which was obtained at three different sites. The highest mixing effects were produced by implements employing tools which rotate in a vertical direction, such as the rotary harrow (operating vertically) and the Finnish rotary harrow.Tools moving solely in a horizontal direction gave low mixing, even if they were driven by the power take off.

The soil relief

An exact sowing depth of the seeds cannot be obtained with an uneven soil relief. Therefore, often roller tillers are attached to the implement for levelling the soil. However, in implement-combinations used for simultaneous secondary cultivation and sowing these roller tillers increase the space required between the cultivation implement and the drill. The result is a comparatively long distance between the tractor and the drill. Thus when mounted implement combinations are lifted, instability of the tractor can follow. The question arises whether the soil relief left by different implements used for secondary cultivation allows drilling without levelling by roller tillers.

The soil relief was measured by means of a reliefmeter similar to the reliefmeter used in previous work of Kuipers (4). The standard deviation of the level of the soil surface was determined. The lower the standard deviation of the soil surface level is, the more even is the soil surface and vice-versa.

The Figures 3 and 4 show the results from two sites. In both cases the Danish cultivator left by far the most uneven soil surface. The reciprocating harrow, on the other hand, produced the most level soil relief. The order of the remaining implements is not the same on both sites and probably influenced by the physical soil properties.

The differences in the soil relief are mainly caused by the tool paths. The Danish cultivator produces distinct furrows and ridges in the direction of travel. The even relief of the reciprocating harrow is mainly a result of the considerable soil transport taking place in the direction of travel as well as perpendicular to the direction of travel. The soil transport in the direction of travel results from a soil ridge, which is carried along in front of the reciprocating harrow. The lateral movements of the harrow bar cause the soil transport perpendicular to the direction of travel.

The preparation of an even soil surface also requires sufficient soil pulverization by the implement. In case the implement tools would not leave any furrows and ridges, the evenness of the relief would depend mainly on the size of the soil aggregates. However, the results in the figures 3 and 4 can only be explained to a very small extent by differences in the distribution of the soil aggregates.

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Table 1: Rank of implements in the mixing effect

	Implement						
	Rot. Harrow (operat. vert.) PTO		Finnish Rotary Harrow	Reci-procat. Sturs	Danish Cultivator	Rotary Harrow (operat. horizont.)	Reci-procat. Harrow
	curved Knives	L-shaped Knives	D	PTO	D	PTO	PTO
site A	1	2	3	4	7	5	6
site B	2	1	3	6	4	5	7
site C	1	3	2	5	4	6	7
Mean Rank	1,33	2,00	2,67	5,00	5,00	5,33	6,67

decreasing mixing effect →

PTO = power take off driven D = drawn

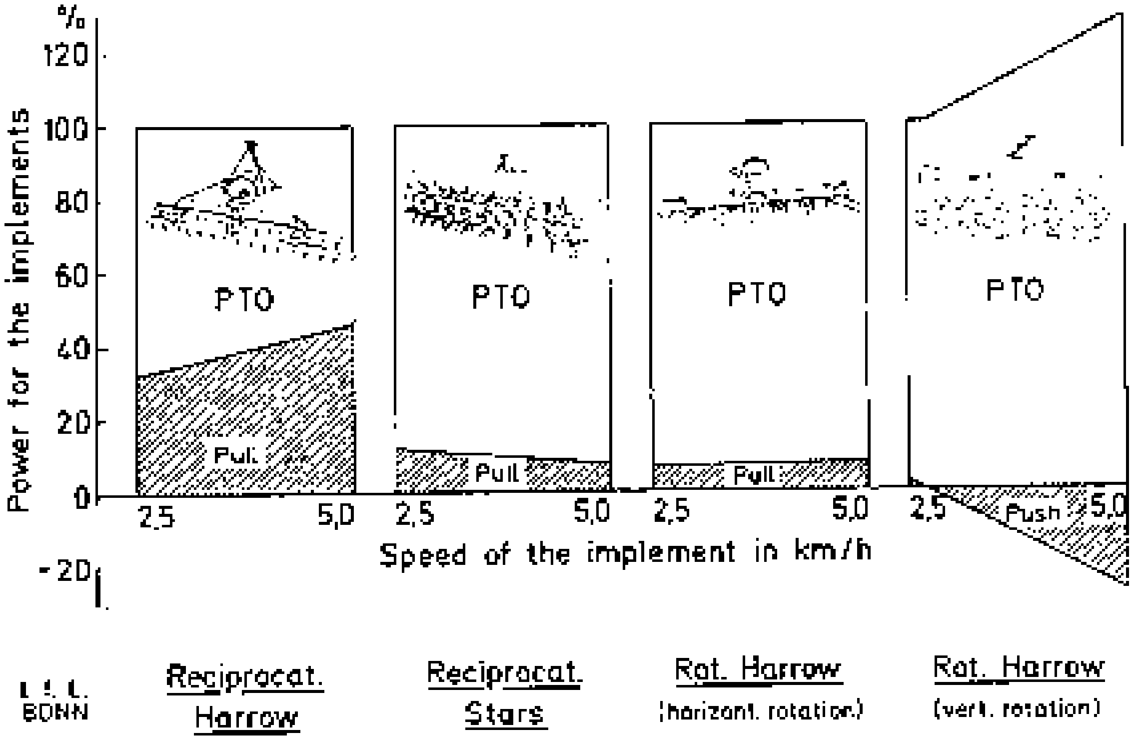

Fig. 1: Power transfer to the implements
Frequency of reciprocating tools: 9 Hertz
Peripheral velocity of rotating tools: 3.6 m/s

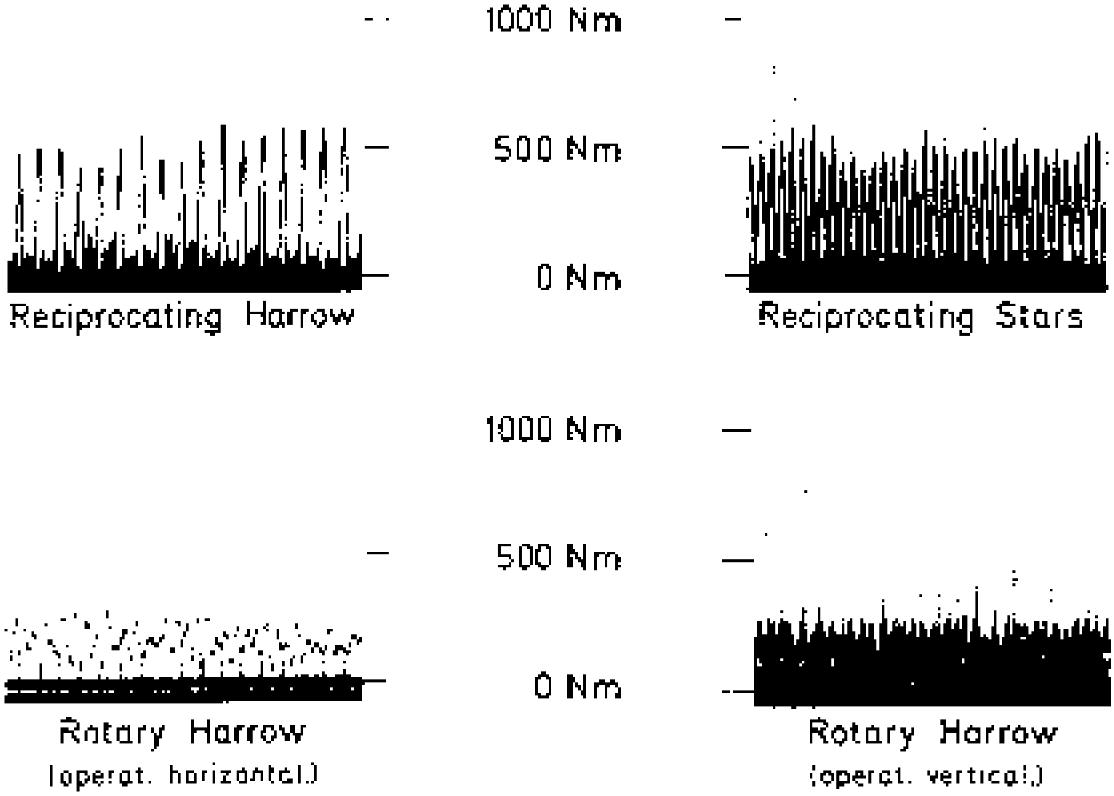

Fig. 2: Torque variation
Forward speed of all implements: 3.5 km/h
Frequency of reciprocating tools: 9 Hertz
Circular velocity of rotating tools: 175-186 RPM

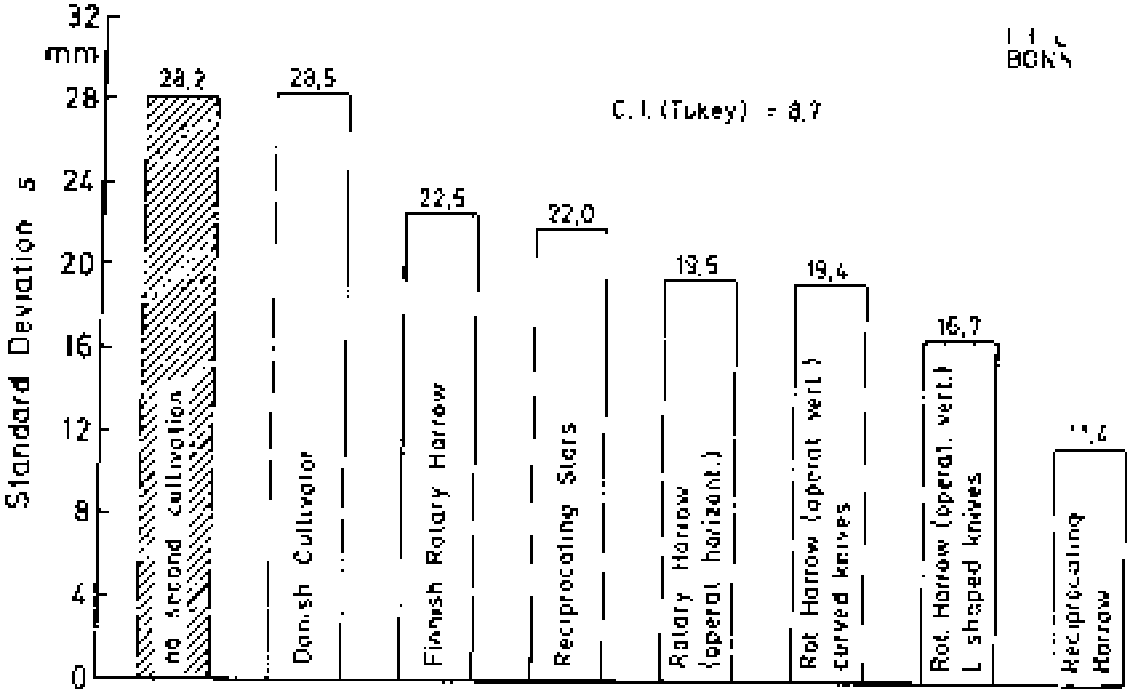

Fig. 3: Soil relief on site A
(loamy sand, plowed 4 months beforehand, 17,5 % water)

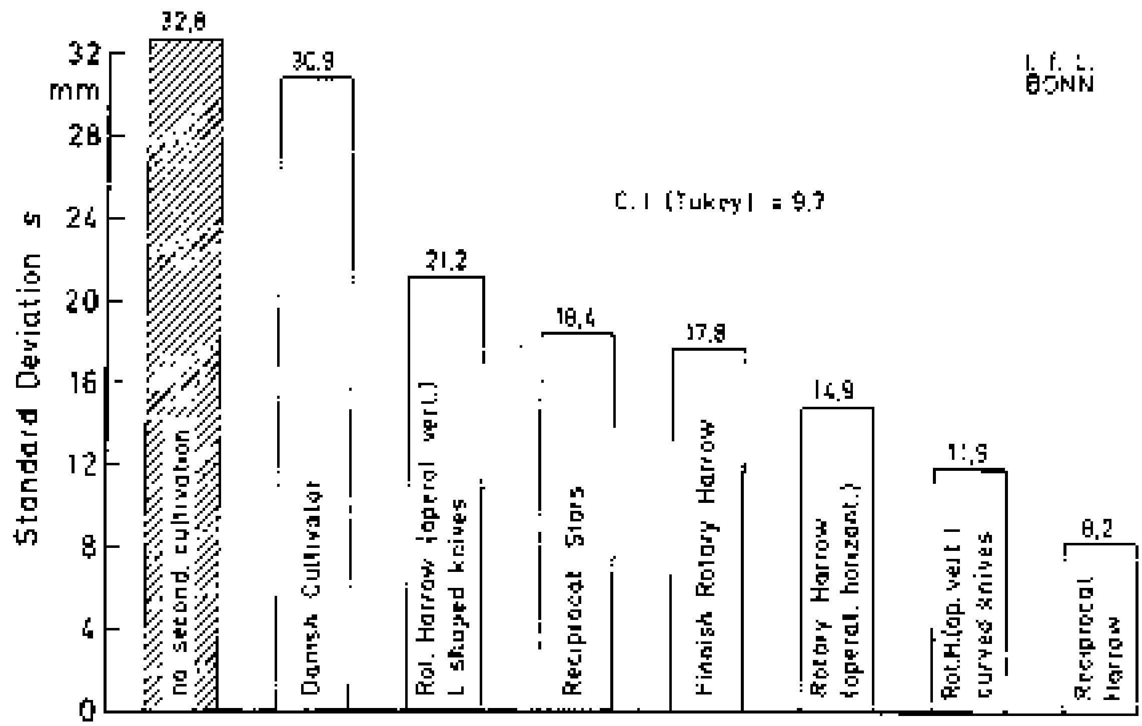

Fig. 4: Soil relief on site 4:
(loamy sand, plowed 4 months beforehand,
16 % water, soil very loose)

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EFFECT OF TILLAGE AND FERTILIZATION OF DIVERSE TYPES OF SOIL ON MAIZE YIELD

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ABSTRACT

Primary tillage and mineral nutrition are not isolated cultural practices. Their effect depends on the relation: soil - ecologic plant conditions - complex of culture practices. Therefore, we have studied on chernozem, smonitza, pseudogley, Brown forest soils and their combinations the effect of: the depth and time of primary tillage, amounts of mineral fertilizers and the plowing under of stubble fields on maize yield.

1. The effect of the depth of primary tillage and fertilization on yield

Method

Soil tillage was conducted at depths of 25 and 40 cm. During plowing soil moisture was found to be: on chernozem 18.39%, smonitza 17.54%, brown forest soil 18.48 and pseudogley 17.96%. The soil was medium moist during tilling, not sticky and suitable for tillage.

Amount of fertilizer:

a) N-75 kg/ha, P_2O_5-60 kg/ha, K_2O-39 kg/ha - total 174 kg/ha
b) N-120 kg/ha, P_2O_5-96 kg/ha, K_2O-60 kg/ha - total 276 kg/ha
c) N-165 kg/ha, P_2O_5-132kg/ha, K_2O-82 kg/ha- total 379 kg/ha

Ratio of fertilizers: 1.0:0.8:0.5 NPK

Simultaneously with seedbed preparation in the fall 75% of phosphorus and potassium fertilizers were plowed under. The remaining quantity and 75% of the total nitrogen fertilizers was taken into the soil during pre-planting preparations. The rest of nitrogen fertilizer was used up during the vegetative period in the 5-6 leaf stage.

The investigation was conducted during 1971/1975. The following types of soil were studied: chernozem, smonitza, brown forest soil and pseudogley.

The maize hybrid under observation was ZP SC 580.

RESULTS

Depth of tillage:

The soil of a heavier granular composition like the pseudogley soil reacted significantly to a greater depth of primary tillage. On the other hand, the types of soil having a lighter granular composition as in the case of chernozem and brown forest soils, no significant reaction occurred to deeper primary tillage. (Fig.1).

Chernozem soil tilled at a depth of 40 cm compared to 25 cm gave greater grain yield by 1.62 mc/ha (1.84%). Similar results were obtained with smonitza and brown forest soils. Smonitza soil tilled at a depth of 40 cm in comparison with 25 cm gave better grain yield by 1.68 mc/ha (2.22%). The effect of a greater depth of tillage in the case of brown forest soil was an increase in grain yield by 2.27 mc/ha (2.96%).

An analysis based on the LSD test shows that differences in grain yield influenced by deeper primary tillage are justified only in the case of pseudogley soil. In the other types of soil the difference is not significant for 5% and 1%.

Mineral nutrition:

The lowest yields in all types of soil were obtained when the smallest dose of mineral fertilizers was applied. With increasing the amount of fertilizers applied in all types of soil, yield was not increased in the same ratio (Fig.2).

In the case of chernozem, smonitza and brown forest soils, there exists a significant difference in grain yield between variants 174 kg/ha and 276 kg/ha of mineral fertilizer. Between the variants 276 kg/ha and 379/kg/ha of fertilizer the difference in yield is not significant for 5% and 1%. On the contrary, on pseudogley soil variant 379 kg/ha compared to 279 kg/ha of mineral fertilizer influenced

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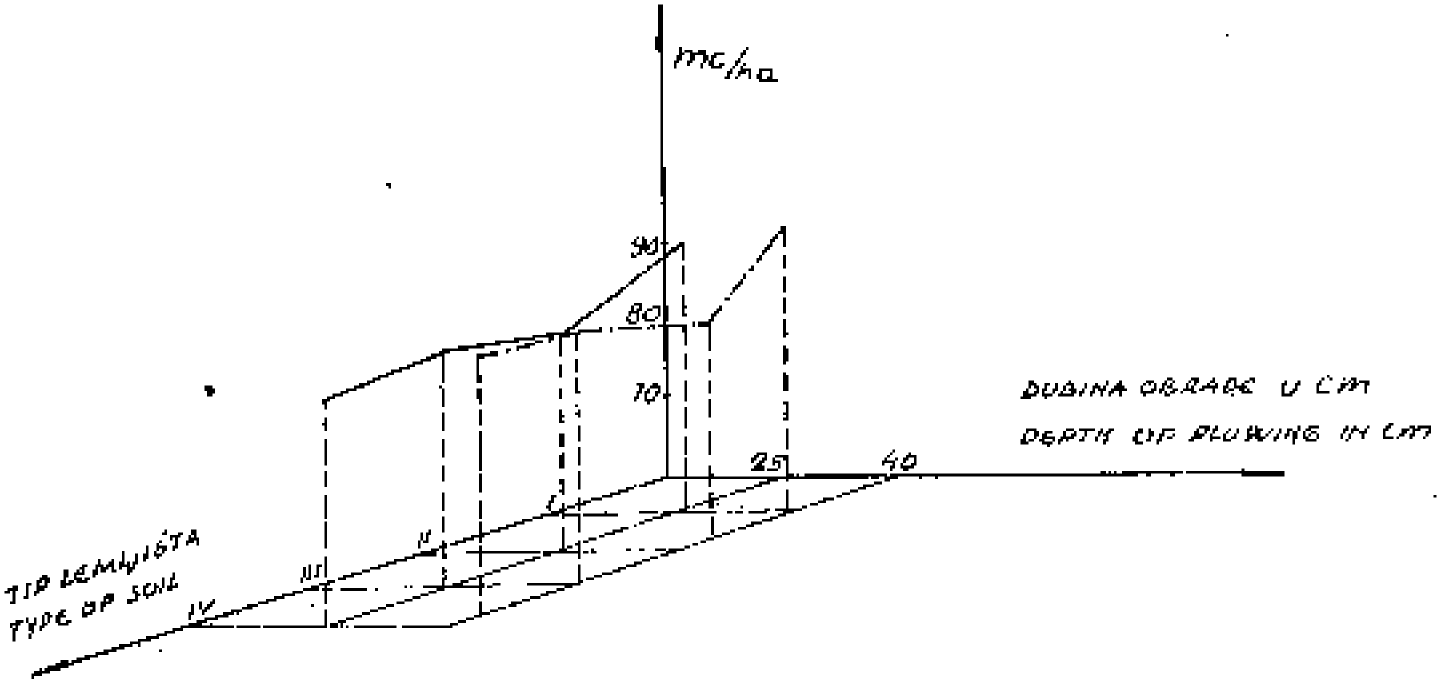
EFFECT OF PRIMARY TILLAGE ON MAIZE YIELD



LEGENDA

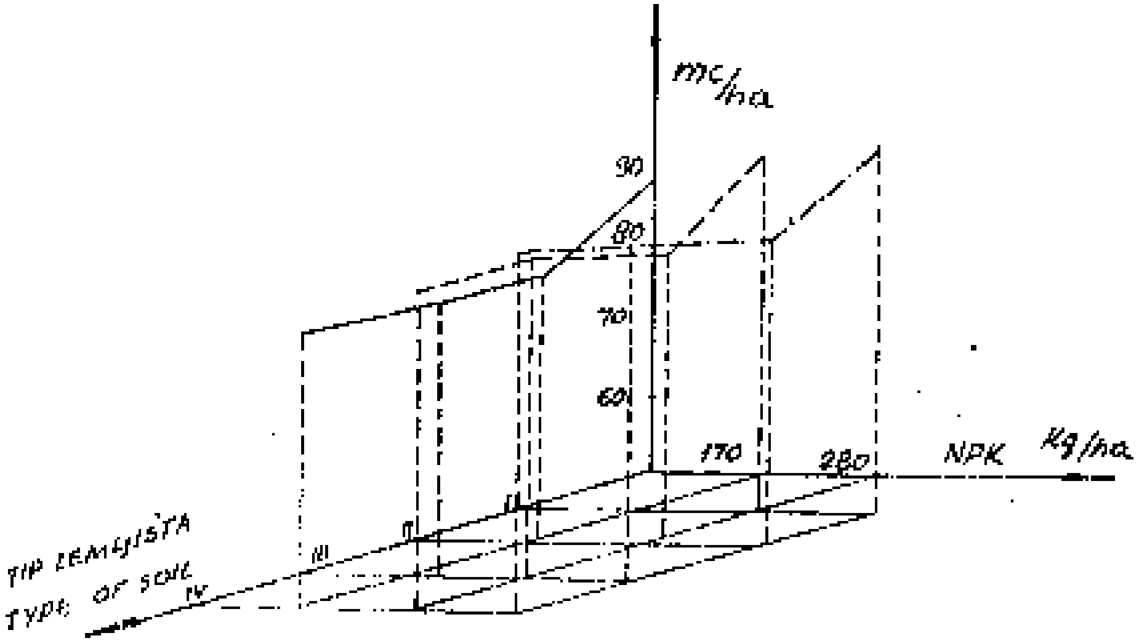
I - ČERNOZEM
II - SMONICA
III - GAJNJAČA
IV - PSEUDOGLEJ

LEGEND

I - CHERNOZEM SOIL
II - SMONITZA SOIL
III - BROWN FOREST SOIL
IV - PSEUDOGLEY SOIL

UTICAJ MINERALNIH HRANIVA NA PRINOS KUKURUZA

EFFECT OF MINERAL FERTILIZERS ON MAIZE YIELD



LEGENDA

I - ČERNOZEM

II - SMONICA

III - GAJNJAČA

IV - PSEUDOGLEJ

LEGEND

I - CHERNOZEM SOIL

II - SMONITZA SOIL

III - BLOW FOREST SOIL

IV - PSEUDOGLEY SOIL

yields significantly. An analysis of pseudogley soil based on the LSD test shows that there is a justified difference in grain yield between the variants 174 kg/ha and 276 kg/ha, as well as between variants 276 kg/ha and 379 kg/ha of mineral fertilizers.

The variant 276 kg/ha of mineral fertilizers compared to 174 kg/ha gave in the average a greater grain yield: on chernozem 3.82 mc/ha (4.13%), smonitza 3.28 (4.28%), brown forest soil 4.76 mc/ha (6.44%) and pseudogley 5.14 mc/ha (7.55%). Between the variants 379 kg/ha and 276 kg/ha of mineral fertilizer, the difference is smaller and was found to be as follows: on chernozem 0.66 mc/ha (0.7%), smonitza 1.15 mc/ha (1.43%), brown forest soil 1.82 mc/ha (2.32%) and pseudogley 4.98 mc/ha (6.80%).

Pseudogley soil in comparison to the other types of soil reacted noteably to greater doses of mineral fertilizers. In relation to the content of physiologically active substances, this soil is compared to the other types of soil very poor. This explains its significant reaction to mineral fertilizers.

2. Effect of stubble field plowing under and the time of primary tillage on yield of hybrid maize of the FAO 500 maturity group

Method

The study was conducted on smonitza soil during the period 1971/1975.

- The stubble field plowed under to a depth of 15 cm immediately after harvesting wheat, primary tillage carried out in the fall at a depth of 30 cm.

- Primary tillage carried out in the fall at a depth of 30 cm without prior plowing under of stubble field.

Stubble field plowed under to a depth of 15 cm immediately after harvesting wheat, primary tillage conducted in the spring at a depth of 20-35 cm.

Results:

As it can be seen from the results in table 1, the greatest average yield was obtained by conducting primary tillage in the fall along with prior plowing under of the stubble field (82.71 mc/ha). Provided the stubble field was plowed under following wheat harvest, yield proved to be higher after spring primary tillage as well (80.34 mc/ha) compared to yield after fall primary tillage without prior plowing under of the stubble field (74.56 mc/ha).

The difference in yield between the different tillage variants according to years ranged between 4.57% and 20.45% (1972).

The investigation was conducted in an arid climate region, where the yearly amount of precipitation corresponded to 206.9 mm (1971), 184.9 mm (1972) and 468.3 mm (1973). Precipitation in the first two years of the investigation represents the limit in maize production under conditions of dry farming. As the distribution of rainfall was quite good, yields were satisfactory, too.

In our earlier investigations (Kolčar, 1974) and in studies of other authors (Marković, 1968; Jovanović, 1969, 1974; Božić, 1973) it was found that at equal soil depth moisture content is greater in the case of deep fall tillage along with prior plowing under of stubble field than without it. This explains higher yield, because in the airid climate a greater quantity of winter moisture is accummulated in the soil when the stubble field is plowed under prior to primary tillage.

Tab.1.- Effect of stubble field plowing under and the time of primary tillage on maize yield

Year	Fall tillage I mc/ha	Fall tillage I %	Fall tillage II mc/ha	Fall tillage II %	Spring tillage mc/ha	Spring tillage %	LSD 5%	LSD 1%
1971	85.28	100	76.04	89.16	82.11	96.28	5.29	8.01
1972	78.08	100	62.12	79.55	77.25	98.93	2.96	3.92
1973	84.76	100	85.53	100.90	81.65	96.33	1.22	1.60
Average	82.71	100	74.56	90.14	80.34	97.13		

I= stubble plowed under
II= stubble not plowed under

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"The 7th Conference of the International Soil Tillage Roserche Organization, Sweden 1976".

Tillage problems for cereal production with respect to different N levels

by

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Summary

Next to numerous advantages, deep tilling also implies a number of disadvantages. Herbicide residues and straw are worked in too deeply, still germinative weed seed is tranported to upper soil layers and, following "good" preceding crops, what is too much N for cereals may be mobilized. The paper explains that shallow cultivation of cereal acreages will help to avoid these negative effects.

I. Various effects of the ploughed forrow may be wholly or partially substituted by mineral fertilizers and herbicides. Reversing of the soil should, therefore, not generally be effected for each type of crop resp. following each preceding crop. Tillage of a weed-free, harvested silage maize plot e.g. transports still germinative weed seed from below to upper soil layers so that new weed control operations become necessary the following year, which would not be required after shallow rotary hoeing.

In the presence of sufficient soil moisture, straw decomposition is most rapid at a depth of 0-10 cm where we in general find the highest degree of biological activity. Deep reversal of the soil would in this case not represent a purposeful type of cultivation. This sort of intervention does, on the contrary, increase the N supply from the soil. On very clayey or sandy soils with a small humus content this would not be appropriate, as the small quantity of humus available in the soil should be preserved. This can best be achieved by letting the soil rest. Intensive cultivation of a soil very rich in humus prior to cereal cropping may also be disadvantageous, as there is a possibility of too much N being mobilized. It is a well-know fact that the flow of N from the soil is influenced by 6 factors:

1. climate 2. weather conditions 3. soil	hardly, if it all, controllable
4. preceding crop	only limited choice
5. soil cultivation	to a certain extent var.
6. fertilization	fully variable

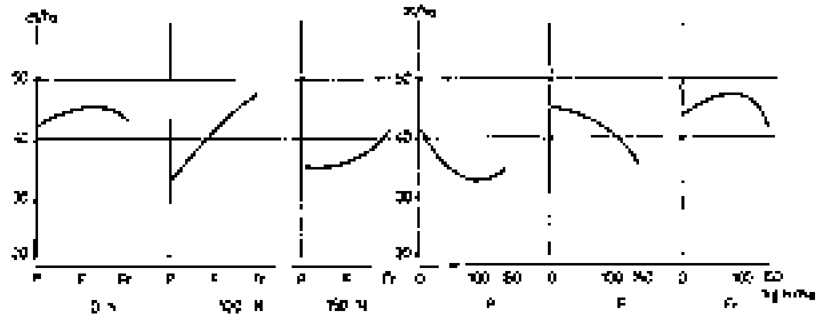
Regulation of the N supply from the soil, following the choice of the preceding crop, is, therefore, possible only by means of soil cultivation and fertilization, an adaptation to the requirements of plants at different growth stages being in the first place achievable by mineral fertilization. Seed-bed preparation does, however, require soil cultivation. On the basis of existing soil cultivation and N fertilization experiments, we tried to determine for our location the most favourable data for cultivation depth and N utilization valid for wheat with maize and rape as preceding crops.

II. We based ourselves on the consideration that in theory with decreasing cultivation depths a) less N becomes plant-available in the soil, and b) the scope of variations in the possible N flow is being reduced (Table 1). This would imply the possibility of reducing the risk of lodging, of deseases and too high protein concentrations in malting barley, and permit to avoid yield depressions. The fact that excessive, unvoluntary

Table 1 Theoretical N supply from the soil (kg/ha) depending on N availability and cultivation depth in the presence of a humus decomposition rate of 1-3%

% N present in soil	cultivation depth 20 cm	5 cm
0.1	30- 90 (Ø 60± 30)	7.5- 22.5 (Ø 15± 7.5)
0.3	90-270 (Ø 180± 90)	22.5- 67.5 (Ø 45±22.5)
0.5	150-450 (Ø 300±150)	37.5-112.5 (Ø 75±37.5)

N supply from the soil may reduce the grain yield became apparent in 1972 during a soil cultivation experiment made with winter wheat following maize on parabrown earth. In the preceding year the maize had been fertilized at a rate of 250 kg of N/ha. Owing to dry weather conditions, the N residue after harvesting was considerable. In the case of ploughed furrow (25 cm) any N dressing of the subsequent winter wheat led to reduced yields. The same held true for cultivator tillage (12 cm) whilst shallow rotary hoeing (4 cm) without N mobilization by soil cultivation produced, in combination with N fertilization, a yield increase. Even without N application, yields increased between 25 and 12 cm cultivation depth in order to start decreasing as from 4 cm.



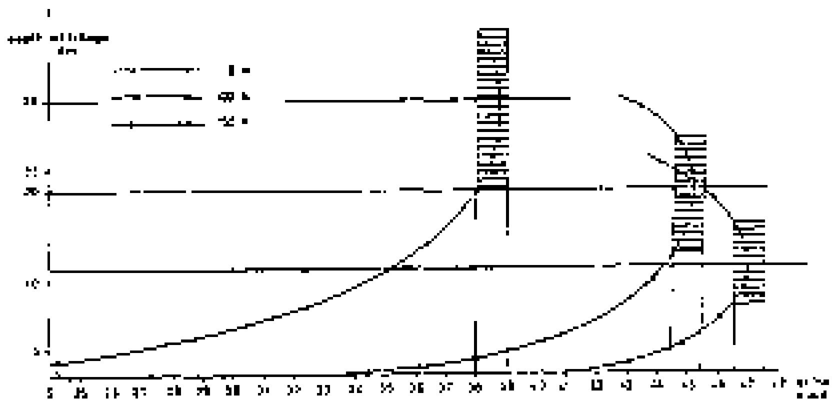
Ill. 1 Winter wheat yields 1972 following maize in the case of ploughed furrow (P), cultivator tillage (F) and shallow rotary hoeing (Fr) with N dressing of 0, 100 and 150 kg/ha.

The experiments continued over a period of 3 years show that under the "normal" weather conditions prevailing in 1973 and 1974 there were smaller quantities of plant-available N present in the soil so that the

optimum cultivation depth without N application amounted to approx 30 cm,

with 100 kg of N/ha it reached approx. 15 cm,

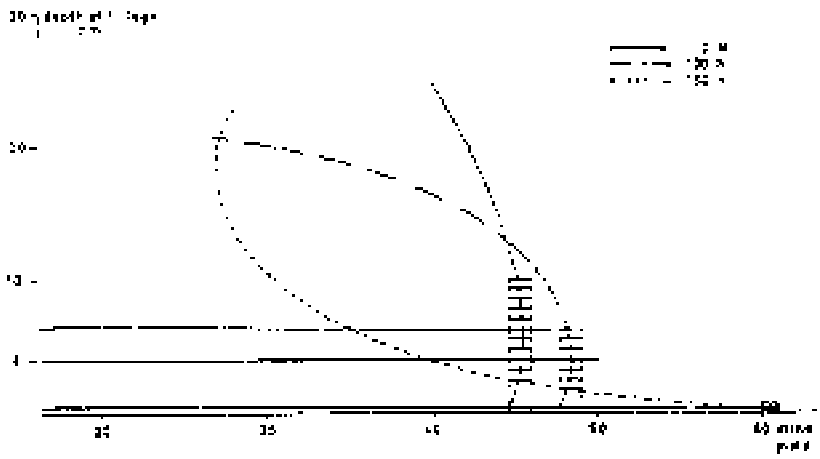
with 150 kg of N/ha approx. 8 cm (Ill. 2).



Ill. 2 Optimum cultivation depth for winter wheat following maize in 1973 and 1974 with application rates of 0, 100 and 150 kg of N/ha.

A very hypothetic curve through the 3 intersections of maximum yields and optimum cultivation levels would show that a maximum yield would have been achieved at a rate of approx. 200 kg of N/ha without soil cultivation.

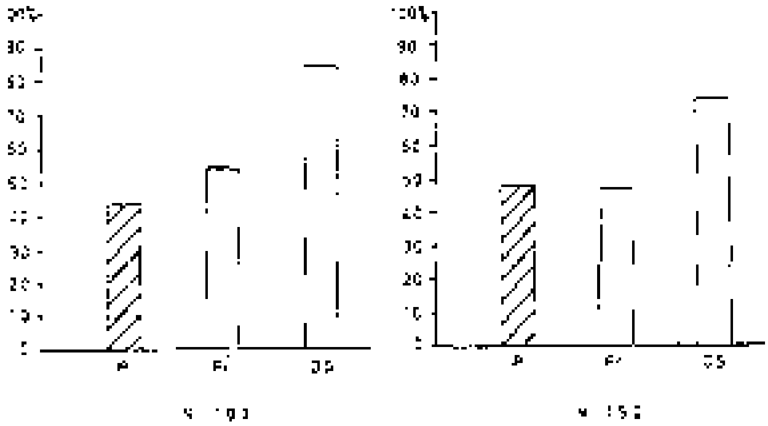
In 1971/72 with dry autumn weather and a mild winter with little rain, on the contrary, the maximum yield would have been realizable without N dressings following a soil cultivation depth of 10 cm only and in theory the maximum yield would already have been achievable with 150 kg of N and zero tillage (Ill. 3).



Ill. 3 Optimum cultivation depth for winter wheat following maize in 1972 with application rates of 0, 100 and 150 kg of N/ha.

In the absence of soil cultivation or following shallow cultivation, there is a smaller amount of N supplied from the soil. Depending on the humus content of the soil, this means that the plant will receive a sufficient dose of N or that the N supply is too small (vide Table 1). As long as the fertilizer rate is in line with the achievable yield level, high N dressings should, therefore, be better convertible into yields in the presence of small N supplies from the soil than if the flow of N from the soil is too high.

Our experiments confirm that the difference between the N quantity determined in the yield/ha and the amount of N absorbed on the zero N plot, which may be considered as utilizable fertilizer N, is bigger following direct drilling than after ploughed furrow. Following ploughed furrow, the N utilization rates resulting on our type of soil reach 45-50% only, in the case of direct drilling the corresponding figures are 75-85% (Ill. 4).



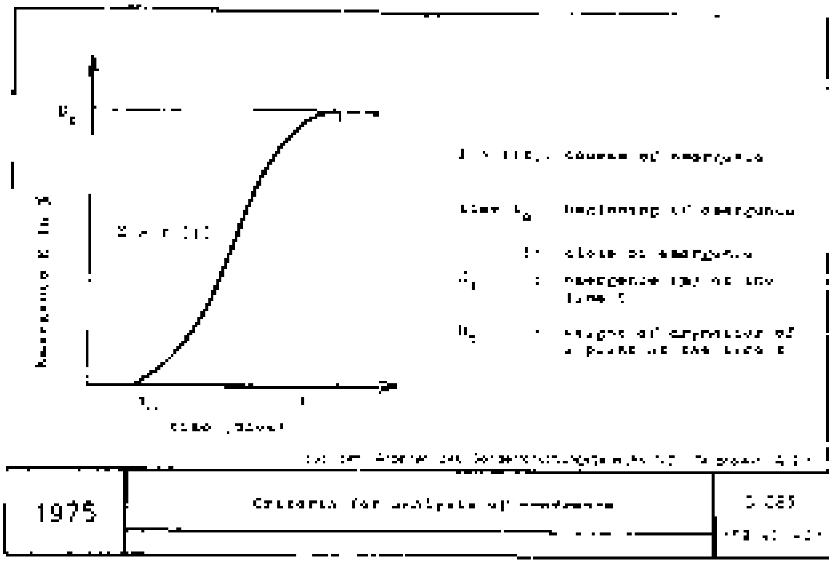
Ill. 4 Utilization of 100 resp. 150 kg of fertilizer N by winter wheat in the case of different cultivation depths (P = 25 cm, F = 10 cm, DS = 4 cm).

Minimum soil cultivation following "good" preceding crops, e.g. rape maize, grass-clover, sugar beet or field beans, does also have a number of economic advantages and labour-saving effects:

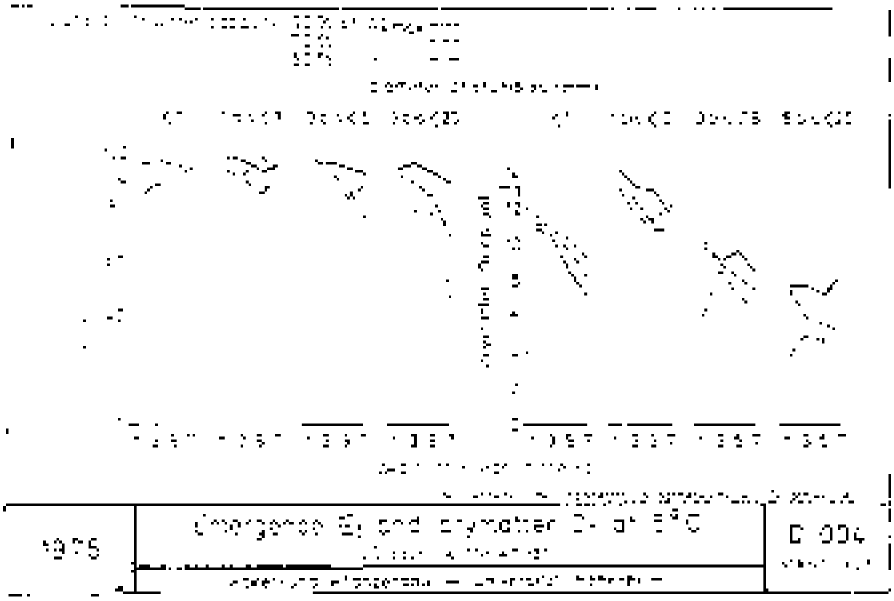
1. Less expenditure of time and energy for soil cultivation and drilling
2. Reduced or no expenditure for chemical weed control if the preceding crop was weed-free (trough herbicides)
3. Better utilization of fertilizer N
4. Harvesting facilities by reduced lodging
5. Possibility of growing the higher-yielding winter cereals even after late harvesting of preceding crop.

At present the problems of minimum cultivation still reside, a.o., in the fact that the seed-bed is often of insufficient quality. In small-scale experiments the field sprouting of winter wheat was determined for the moment t (Ill. 5), this for various aggregate sizes, degrees of water saturation of the soil, drilling depths and temperatures. Under the given soil and test conditions, a high degree of field sprouting, almost independent of drilling depth an soil moisture, was obtained only with aggregate sizes between 1-3 mm Ø (Ills. 6/7). In the case of more finely divided soils, high soil moisture, low temperature and higher drilling depths, however, field sprouting amounted to approx. 25% only. On a dry soil and following very shallow or very deep drilling, shooting again reached no more than 30-40%.

Ill. 5



Ill. 6



Consequently, minimum cultivation is more indicated following good preceding crops on soils with a satisfactory crumb structure, resp. on sandy soils or soils rich in humus than on clayey acreages insufficiently prepared by bad preceding crops.

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The 7th Conference of the International Soil Tillage Research Organization, Sweden, 1976.

Grassland renovation

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ABSTRACT

In laboraty- and fieldtrials the germination of grass seed was studied in relation with sowing-depth and soil compaction.
Sowing at a depth of 2 - 3 cm is to prefer above superficial sowing.
Soil compaction has some positive effect after superficial sowing.
Soil moisture content however is the most important factor for germination.

RESULTS

Laboratory experiments

Under conditioned circumstances (temp. $\pm$ 15 $^{\circ}$C, relative air humidity 40 - 60%) experiments were done in three repetitions with different soil types (clay, sand and peat), two sowing-depths (0 and 2 cm) and with more or less soil compaction (experiment I: 0, 1, 2 and 3½ kg/cm^2 and experiment II: 0, ½, 1 and 2 kg/cm^2); no water or nutritions matter was applied. The results are shown in fig. 1. We see that:

a) a sowing depth of 2 cm is better than 0 cm.
b) Soil compaction at a sowing depth of 2 cm has a negative effect on the germination.
c) On the objects of 0 cm sowing depth compaction has a possitive effect; more pressure gives a better result. Probably the contact between seed and soil is better due to compaction and the young plant can get more water.
d) on clay the germination is not so good as sand and peat. Without soil compaction the contact between seed and soil is rather bad and with compaction the mechanical resistance may be to high for germination.

FIELD EXPERIMENTS

In the field about the same experiments as in the laboratory were done to see the reaction of germination under practical circumstances.
On a sandy soil the seedbed is prepared with a plough and a cultivator and with a special rotary tiller (buryvator, reverse rotation, see the paper of Mr. U.D. Perdok: Multi-powered soil tillage implements).
With a sowing machine the seed is placed superficial (0 cm) and at a depth of 2 - 3 cm. After sowing the soil is compacted with a pressure of 0, 1, 2 or 3 kg/cm^2 by using a flat roller (ballasted with water-filled containers).
The results, shown in fig. 2, are:

a) the sowing depth of 2 - 3 cm is much better than superficial sowing (as in the laboratory experiments)
b) superficial sowing on the plough objects gives more sprouts than on the buryvator objects; on the rugged position of the ploughed surface the seed depth is about 1 cm instead of 0 cm (specially after raining)
c) soil compaction has some effect on the ploughed objects with superficial sowing and perhaps on the buryvator objects with 2 cm sowing depth. On the other objects compaction has hardly any effect.

Other fieldtrials showed the difference in sowing-depth between the various machines used for grassland renovation (fig. 3).
The well-known machine, Brillion, sowed in the upper layer (0 - 1 cm).
A flax-sowingmachine (with pipes) can place the seed at a depth of 2 - 5 cm.
A special machine for grassland renovation is the sowing-buryvator.
In this machine the operations are combined. The buryvator is equipped with a sowing mechanism for grass seed and with a roller. This machine is sowing at a depth of 0 - 2 cm.

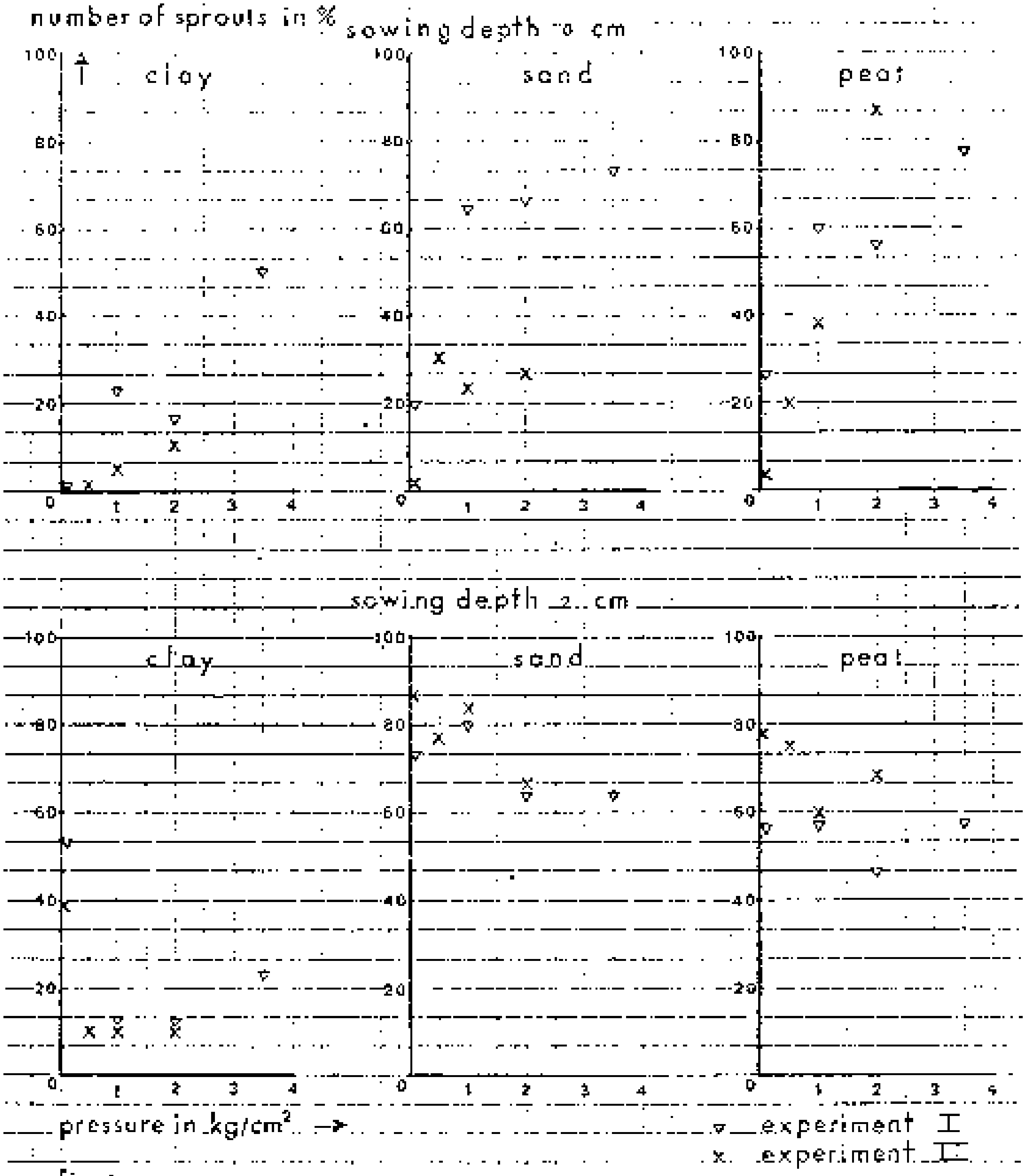

Fig. 1

Number of sprouts in connection with sowing depth and pressure.

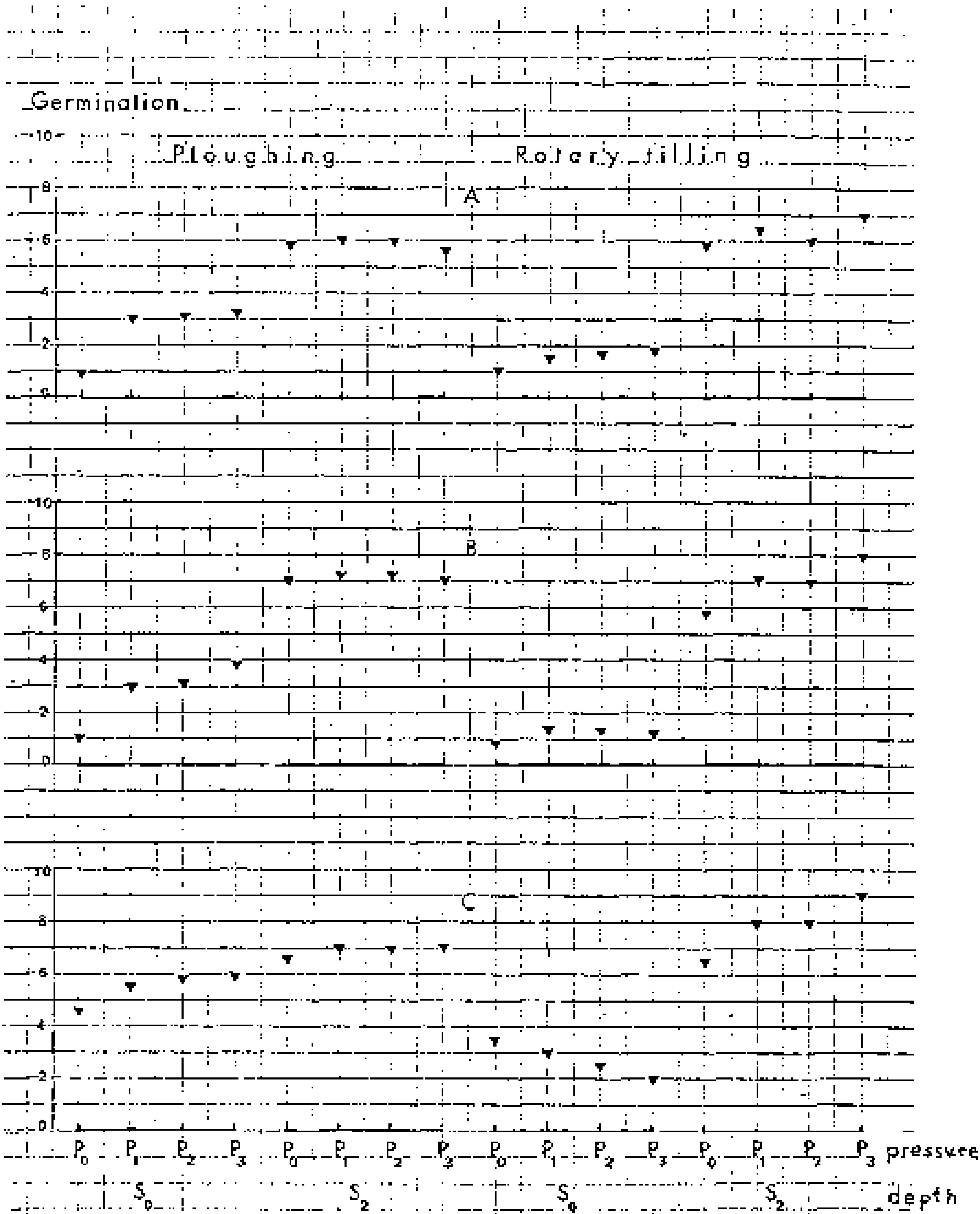

Fig.2

Visual review of the objects expressed in valuemarks at 3 different data:
A = 27/8, B = 5/9, C = 19/9.
Sowing date: 15/8
Valuemark 10: object with many sprouts
Valuemark 1: object without sprouts

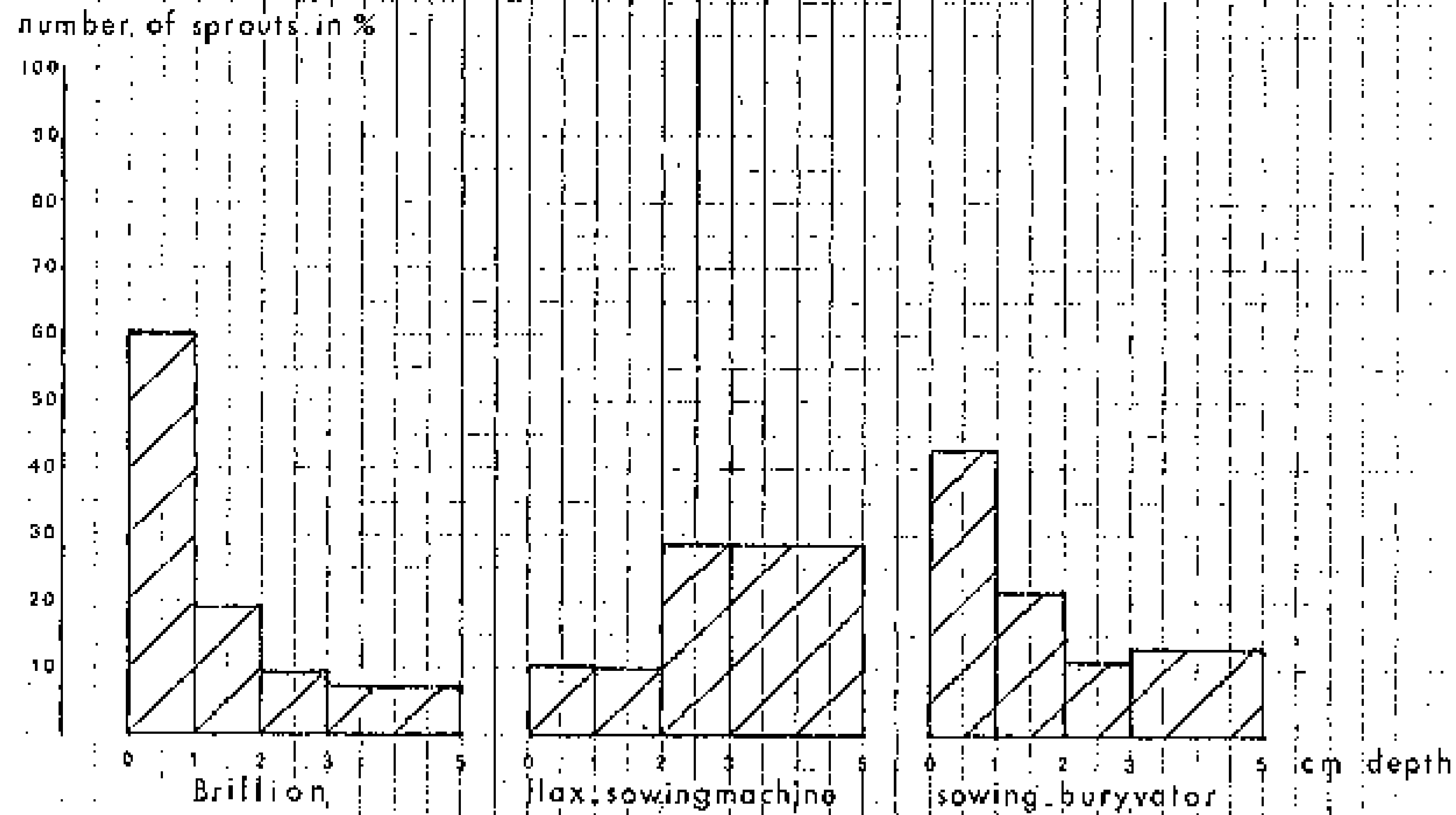

fig.3

Sowing depths of different sowsystems.

The 7th Conference of the International Soil Tillage Research Organization, Sweden, 1976.

Relation between Specific Energy and Clod-Size-Distribution of a Rotary Tiller.

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Abstract:
Energy requirement for tilling and tilling effect are critical factors for a soil implement. An attempt to develope a relationship between energy and degree of pulverization was very close. Therefore we can use the quotient of both energy and effect as a characteristic of an implement. It is proposed the new index to be named 'specific energy of pulverization'.

1. Problem of soil tillage

Preparing an optimal seed-bed is the main objective of soil tillage. On the one hand clod size distribution controls the germination on the other hand the soil moisture content influences the pulverization. Therefore it is necessary to adapt the tilling effect to the conditions of soil. The best implements for varying the tilling effect are powered machines, e.g. rotary tiller, oscillating or rotary harrows.

Although we can vary the effect of powered implement by changing the rotation speed or forward velocity, there are many factors influencing the tilling effect. The initial soil conditions, especially the soil moisture, may [illegible], determine both how well it is broken up and the power requirement. But these two factors are to be regarded, if an implement should be characterized.

Formerly energy requirement and tilling effect were measured mostly separately. Gill [illegible] was the only one to try to connect the two critical factors. He found a nearly linear function, which would allow using the quotient as a characteristic of a soil implement. [illegible] only in the last years th

[illegible] the remaining influence [illegible] power re-
[illegible]

[illegible]

[illegible]

The [illegible] produced per unit time [illegible] is the product of tilling depth [illegible], width [illegible] and the working velocity [illegible]. The power (P) is the quotient of energy [illegible] and time (t).

(4) [illegible]

[illegible]

[illegible]

The use of [illegible] as quotient [illegible] the only characteristic of implement [illegible] at constant tilling effect. At different clod size distributions it is necessary to recover the degree of pulverization.

The degree of pulverization (DP) is given by the mean weight [illegible] (MWD). It is the reciprocal index of MWD (Pritchard, [illegible]):

(5) [illegible]

[illegible] the requirement of specific energy is [illegible] the degree of pulverization, we can calculate an index [illegible] as follows:

(6) [illegible]

[illegible] specific energy of pulverization.

?.? Treatment

Four times during two weeks a sandy loam was tilled by a rotary tiller. The moisture of soil became less by dry climate. So it was possible to work at different content of soil water. The tilling effect was varied by forward velocity from [illegible] to [illegible] m/s at constant rotation speed of [illegible] rpm. The length of bite was between [illegible] and [illegible] cm.

The draw force was measured at the lower links, the power to drive the rotor at the power take-off ([illegible], 19[illegible]). The necessary energy = sum of draw and rotation power = was spent only for the pulverization by the tools of implement.

The clod size distribution was determined by sieving air dried clod samples at once after tilling ([illegible], 19[illegible]).

3. Results

3.1 Influence of tilling pitch on the clod size distribution and power requirement

The tilling pitch has a great effect on the degree of pulverization influenced by variation of forward velocity at constant rotation speed. In the range from [illegible] to [illegible] cm a regression function was found (Fig.[illegible]). They are statistically significant. It shows that increasing velocity and pitch results in a lower degree of pulverization which fall on a constant level, when the tilling pitch exceeds [illegible] cm.

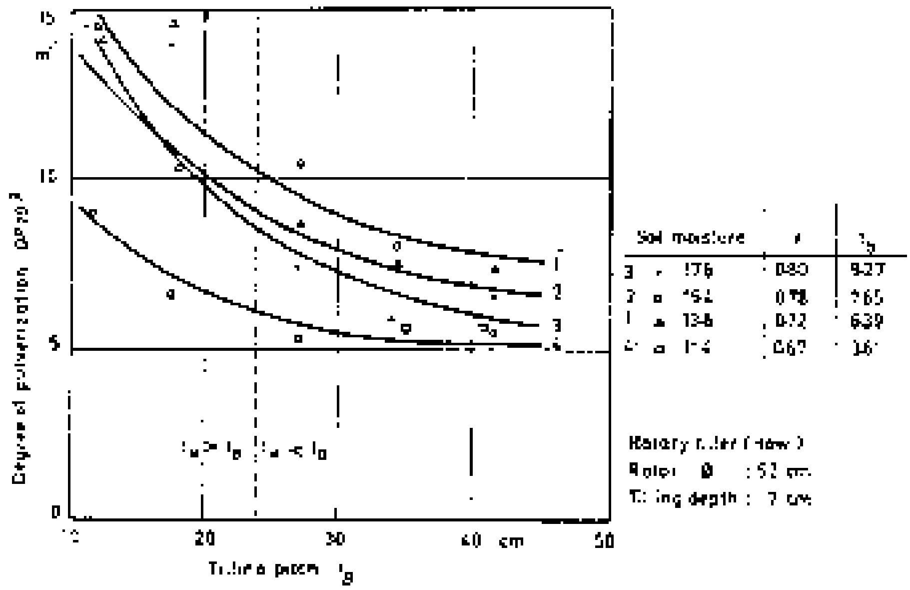

Fig.?, Influence of tilling pitch on the clod size distribution ...

The different level was caused by different soil moisture content [illegible] tilling. The finest clod size distribution was produced at [illegible] content of 17.6 % (g/g). Lower or higher soil moisture decreased [illegible] effect of tillage. The influence of soil moisture content on [illegible] tilling effect will be published in another work.

[illegible] the same function [illegible] for the relationship between [illegible] energy and tilling pitch (Fig. 4). The specific energy [illegible] with [illegible], when tilling pitch increased.

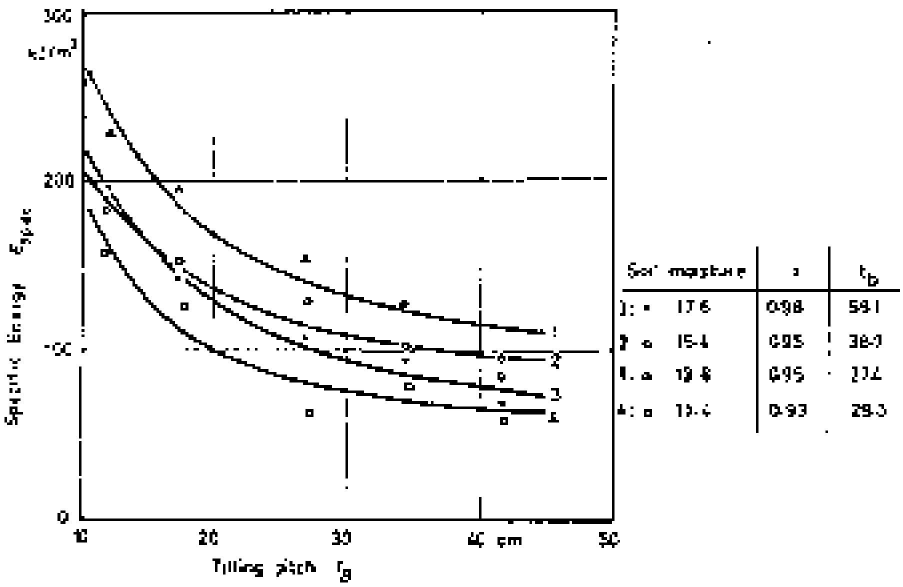

Fig. 4 Influence of tilling pitch on the specific energy (according to Zeltner)

[illegible] (1940), who studied the specific energy as a function of tilling pitch, we found the same result, that increasing pitch [illegible] lead to lower consumption of energy.

If we compare the two functions, then we can see a similar influence of tilling pitch on the degree of pulverization and specific energy. [illegible] tried to correlate the two indices. [illegible] shows [illegible] correlation of high statistical [illegible] (r = [illegible], t_b = [illegible], n = [illegible]). It is a linear function [illegible] goes through the point of zero. [illegible] tilling effect will increase with increasing [illegible]. [illegible] energy is spent, there will be no [illegible].

[illegible] equation (5) it is possible to calculate the specific energy of pulverization from the function (Fig. 3).

$$DP \cdot 10^3 = 0.071 \cdot A_{spec}$$

$$P_{spec} = \frac{A_{spec}}{DP} = \frac{1}{0.071} \cdot 10^3 \qquad P_{spec} = 14.1 \cdot 10^3 \; (kJ/m^3)$$

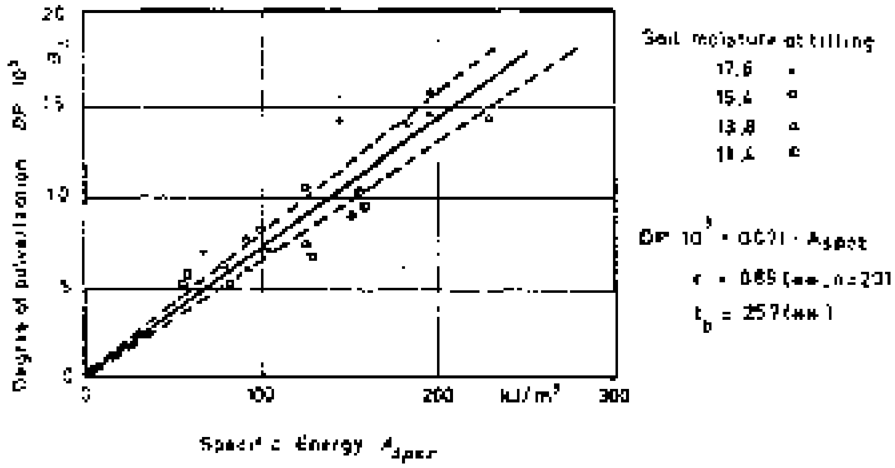

Fig.3, The relation between specific energy and degree of pulverization of a rotary tiller.

The new index (P_{spec}) includes two important factors to characterize an implement of soil tillage. It shows how much energy is required to produce one degree of pulverization per unit of soil volume.

4. <u>Conclusion</u>

A desired clod size distribution can be achieved by varying the tilling pitch of rotary tiller. But the finer the clods shall be, the more power is required. The power requirement is proportional to the degree of pulverization. It was surprising that the function was independent of soil moisture content. This fact indicates a close connection between crumbability of soil, effect of tilling and power requirement.

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The 7th Conference of the International Soil Tillage Research Organization, Sweden, 1976.

Determination of the Upper Tillage Limit for spring tillage by a lab-test.

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Abstract.

A method is described imitating the effects of spring tillage on a micro scale. By treating a series of samples with increasing moisture content, observing the results, the critical moisture content is found. The grading is done by observation and can be quantified by measurement of the pull of a spatula and by sieving after drying. Acetone drying and sieving did agree best with observation. The method was calibrated against the moisture content at spring tillage of [illegible] fields belonging to [illegible] experienced farmers.

Introduction.

In Holland the spring tillage has to provide results which can be used at once. Often the soils are too wet for successful tillage but postponement of seeding can result in a decrease of yield up to 1 percent per day, Wind 1960. The farmers try therefore to prepare the seedbeds as soon as possible. The results of tillage are consequently limited by the smearing and puddling occurring when a soil is too wet and soft to be worked and driven over. Though most farmers are quite able to chose the right moisture content some need of objectivation exists, especially with a view to forecasting the right moment of spring tillage.

Method.

In order to be applicable at all the method must be cheap necessitating only a small quantity of soil, e.g. 1 kg. The last condition implies that the dimensions of the model field must be small also. The small dimensions of the field e.g. [illegible] cm imply that only small velocities can be used, cm/sec instead of m/sec. The instrument forces which act chiefly in a horizontal direction are substituted by a force with a larger compressive component also the action has to be repeated.

Principle.

Duplicate soil samples forming a series of moisture contents are worked in a standard way. The results are evaluated by sight and may be quantified by pull measurements and sieving. The moisture content 1 % below the moisture content at which the aggregates are enlarged and the pull increases sharply is regarded as the maximum moisture content for spring tillage, the Upper Tillage Limit.

Preparation.

The aggregate fraction 2-4 mm is sieved out, after freezing and drying if necessary. Six to 10 portions of 20 g are filled into pre-weighed stainless steel dishes 7 cm wide, fig. 1. The aggregates are tapped into a tight packing with the aid of a tightly nailed plank or flower pricker. A series of moisture contents is established covering the range from pF 4 to -2 or 1.5 in steps of 2 %. The water is applied evenly and dropwise from a 10 ml pipette graduated to the tip. The dishes are covered and left to equilibrate overnight in a saturated atmosphere.

Treatment.

As tool is used a 200 g hammer with a bevelled head, see fig. 1. The weight of the hammer pivoted 20 cm from the head is 190 g, its cross section area is 0.55 cm^2 and the pressure 80 mbar. This hammer is dragged 80 times across the dish, half way with respect to the far end; each time the dish is rotated a 180°. Care is taken not to apply any extra compressive force. The velocity is about 1 cm/sec. Adhering soil is scraped off at the inner side of the dish. After the test the moisture content is determined using the dish. Changes in soil structure during the test are recorded.

Classification.

The aim of the tillage being to break up clods the resulting structures are classified according to aggregate size. 0 means nothing has changed, e.g. dry clay soil. This mark goes up to +5 according to the percentage having a diameter ½ or less than the original. When the soil is getting too wet an increasing portion adheres to the bottom and the marks are lowered accordingly passing through zero. If all of the soil has been converted into a stiff shiny mass the mark is -5.

Quantification, supplementary.

The results can be quantified by measuring the pull or the size distribution by sieving. As the latter method is rather time consuming the information gained will not always warrant the expenses.

I. Pull.

With moisture contents above the U.T.L. on working the fine fragments of the aggregates are stuck one to another and to the bottom of the dish. The pull then increases abruptly with increasing moisture. The pull is measured with little cost using the set up pictured in fig. 1. A rectangular spatula 0.5 cm wide is pushed vertically into the soil where the thickness corresponds with the average. The spatula is then pushed away from the balance and the gram force is recorded, see figs. 3 and 4. Conversion of pull into shear strength. The pull of the spatula can be converted into shear strength using Mann's formula (1974) (also Payne 1966) τ_b = g.f./4.54 d, where d = thickness of the soil layer in cm. The latter is measured with a calipher.

II. Size distribution.

To obtain a soil which can be sieved it has to be dried first. During drying small fragments are often cemented to larger ones. To prevent this cementing the water can be replaced by acetone before drying.

II.1. Cheap sieving procedure.

The aggregates are divided into three classes: unaltered-smaller-larger. As small changes in form allow a sieve fraction to pass through the lower limit sieve, the range of "unaltered" has been enlarged to 1-4 mm. The effect of acetone drying as shown in fig. 3 is not striking. The method does not register fully the changes as observed, upper part graph 3.

II.2. Complete sieving analysis, Relative Clod Surface Area.

The soil is sieved through a range of sieves from 10 mm down to 0.25 mm. As permeability, velocity of base exchange, accessability to plant nutrients and strength depend partly on the specific exterior surface area of the aggregates, the latter is chosen as parameter.

The Clod Surface Area is found by multiplication of the weight of the size fractions with their specific exterior surface area, dividing the sum of the areas by the sum of the weights. The specific exterior surface area of a size fraction with diameter d and density ρ_b is $S_c = 6d^2/\rho_b.d^3$ (cubic form), so $S_c = 3.33/d$. The mean diameter of a sieve fraction is assumed to equal the lower diameter plus 1/3 of the range. As the assumptions as to form and density may not hold, the Relative Clod Surface Area may be a better parameter, i.e. the factor by which the surface area of the original sieve fraction has been changed.

Example.

In fig. 3 the visual observation the pull and the quick sieving of soil 92, 32 % clay, 3 % humus, 2.1 % lime are plotted against the moisture content. The agreement between observation and sieving is only fair, the top at 21 % not showing with the latter. The results deteriorate between 23 and 25 % and the pull rises sharply there, therefore the critical value is 24 % and the U.T.L. lying 1 % below equals 23 %. When the pF curve is available it is of advantage to plot the data against the pF value as in fig. 4. Both limits lie close to pF 3, which means that some sharp drying has to occur before the soil can be tilled. The R.C.S.A. as determined with acetone agrees best with the observations.

Calibration.

The number of "drops" of the hammer was found as follows. Twenty samples were collected by U.D. Perdok with the moisture contents at spring tillage. The clay content ranged from 14-46 % and the humus content from 1.- to 5.- %, all were calcareous young polder soils. The samples were prepared as described. The moisture content of one sample was brought to 1 % above the tillage moisture and treated with the hammer. It proved that with 50 "drops" of the hammer a dense structure was obtained. This number was applied to all soils with the result as shown in fig. 5 and equation 1.

$$U.T.L. = 1.05F + 3.61 \quad r = 0.924 \quad F\ (r > 0.59) = 1\ \%$$

(F = field moisture at tillage).

That the relation is slightly askew is caused by the first 7 samples from Flevoland, the youngest polder. The ripening had not come to an end in the polder but did so during drying in the lab. This explanation is corroborated by Perdok (1975) who using an U.T.L. determination based on air permeability after standard compression found U.T.L. = 1.03 F + 2.17, the same Flevoland samples lying to the right of this equation. The relation of the U.T.L. to the composition of the soil is

$$U.T.L. = 0.34\ \%\ clay + 4.77\ \%\ humus; \quad r_{z,xy} = 0.910$$

Acknowledgement.

The author wants to express his thanks to P. Koorevaar for the mathematical treatment.

Litterature.

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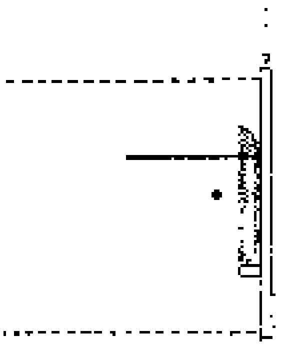

Fig. 2

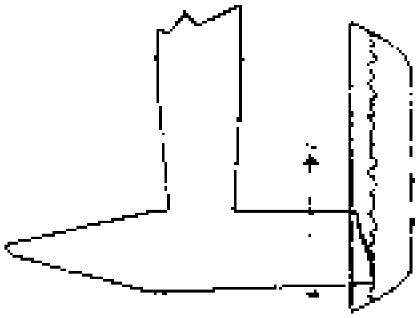

Fig. 1

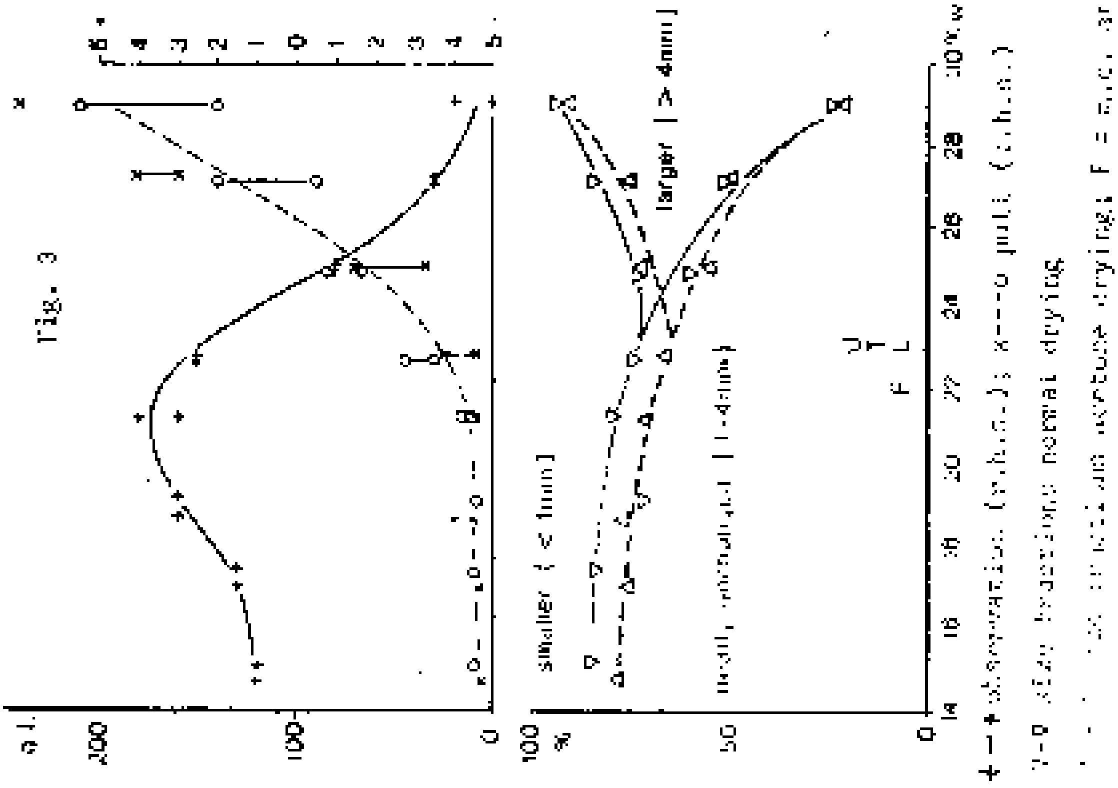

Fig. 3

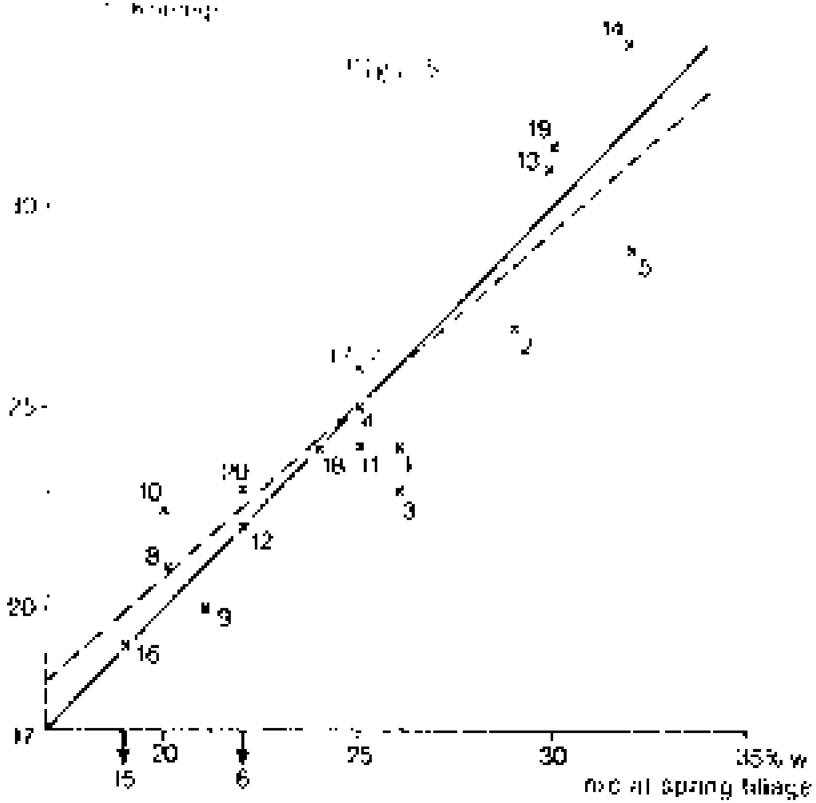

Fig. 5

—— [illegible] spring tillage

regression line

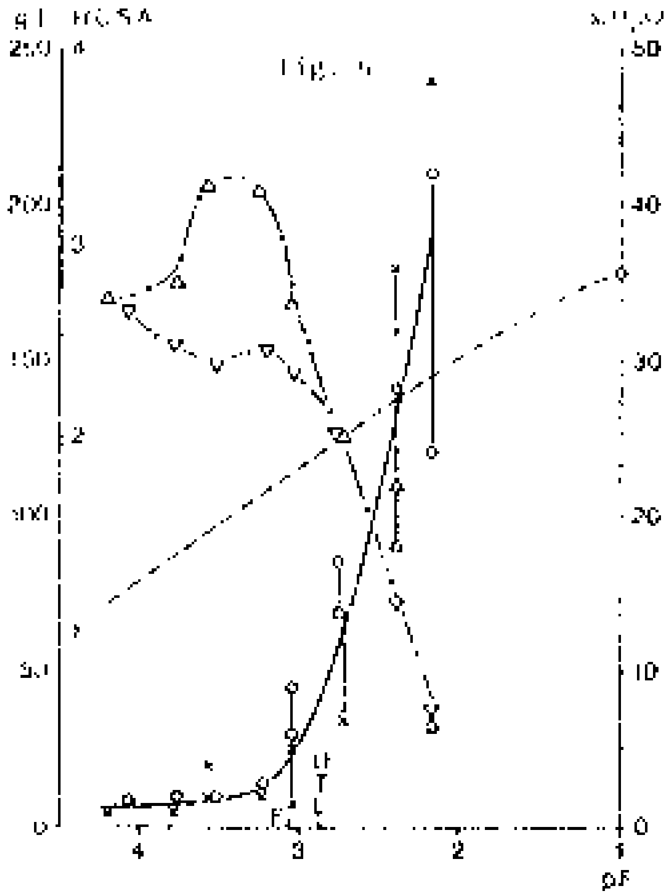

Fig. 6

--- pF curve; —— [illegible]

Rel. Clod [illegible]

V normal drying; Δ [illegible] drying

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Mechanical properties of precompacted soil as affected by the moisture content at precompaction.

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ABSTRACT

Compaction at seed-bedpreparation affects the resistance of the soil to further compaction at inter-row cultivation and harvest, as well as the energy needed for tillage to loosen the soil after the harvest. These interrelations are not yet fully understood. The present paper is intended as an introduction to the problem, offering a basis for solutions and providing information on the strength of compacted soil as affected by the moisture content where compaction occurred.

INTRODUCTION

At the start of a growing season, the soil is compacted by field operations. During inter-row cultivation and harvest, the soil may be additionally compacted. After the harvest, energy is applied to loosen the soil again. To make cropping as optimal as possible (i.e., to reach maximum profits), it is necessary to know how these three sets of operations influence each other. This paper is intended as an introduction to the problem of how the soil moisture content prevailing at the start of the compacting seed-bed operations (precompaction) influences firstly any further compaction occurring during inter-row cultivation and harvest, and secondly the amount of energy needed for soil loosening after harvest.

RELEVANT MECHANICAL PROPERTIES OF SOIL

Soil loosening by a plow and soil compaction under wheels are processes depending on: properties of the plow and wheel; system properties such as working depth, travelling speed, etc.; and mechanical properties of the soil pertinent for the process in question. The ways in which the processes in question depend on these properties form a subject formally called soil dynamics in tillage and traction.

Many methods are available for measuring the mechanical properties of soil, including tensile strength determination, the unconfined compression test, the tri-axial test, the uni-axial compression test, and the compaction test applying hydrostatic pressure. Indications have been obtained that the unconfined compression test is preferable for soil-loosening processes and the uni-axial compression test for compacting processes.

<u>Uni-axial compression test.</u> In this test a piston which gradually compresses soil in a cylinder is used (fig.1a).

By measuring the mean pressure on the piston (σ_1) and the soil porosity (P) continuously during the test, a σ_1-P relationship can be determined. The lateral strain is zero and the σ_3/σ_1 ratio is about 0.5. From the stresses within a soil mass under a wheel, the largest principal stresses σ_1 can be estimated with reasonable accuracy, but the σ_3/σ_1 ratios are not known. However, our calculations on data measured in tri-axial tests by other authors (1,2) indicate that the σ_1-P relationship is not greatly affected by the σ_3/σ_1 ratio. Therefore, the σ_1-P relationship measured in a

uni-axial test can be considered valid for compaction under wheels. This test has the advantage of being relatively simple to perform.
Unconfined compression test. In this test a soil cylinder(height 10 cm, diameter 5 cm) is failed by two pressing plates(fig.1b), and both failure stress σ_f and failure strain ε_f are measured at the moment of failure.

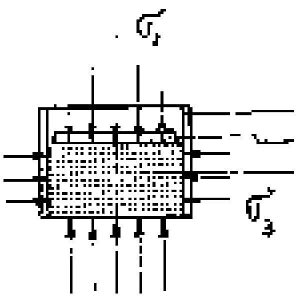

fig. 1a

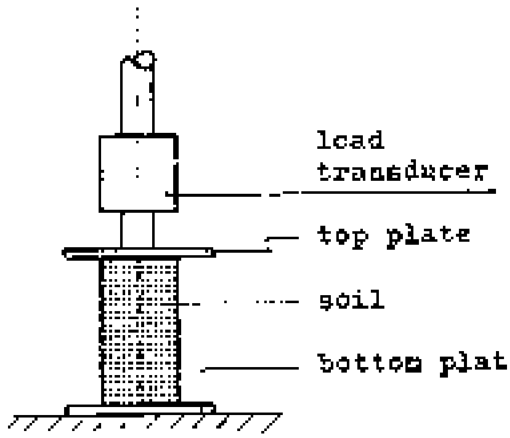

fig. 1b

For a small curved blade operating in several types of soil, the kind of soil failure(shear-plane failure, steady cutting, or open crack formation) could be predicted from σ_f and ε_f (3). In scale model research with earthmoving equipment, "scaling" of soil strength was quite successful on the basis of σ_f and ε_f (4). The unconfined compression test too is relatively simple. On the basis of these findings it is concluded that: compaction involved in seed-bed preparation can be simulated by uni-axial compression of initially loose soil, uni-axial compression of precompacted soil simulates further compaction at inter-row cultivation and harvest, and soil loosening after harvest can be simulated by the unconfined compression test.

DETERMINATION OF THE EFFECT OF THE MOISTURE CONTENT AT PRECOMPACTION

The moisture content(m.c.) at precompaction affects the strength of precompacted soil via two phenomena: 1) the m.c. at precompaction influences the degree of compaction reached at precompaction, and 2) the m.c. at precompaction influences the micro-structure of precompacted soil.

Since the first of these phenomena has been investigated extensively, but the second much less, the following is confined to strength effects of the m.c. at precompaction to the extent that strength effects were measured in precompacted samples having equal porosities and equal moisture contents at the time of testing. The data derive in part from the literature and in part from research done in our laboratory. For the sake of completeness, these data are not confined to uni-axial and unconfined tests.
Moisture content is expressed as a percentage of dry weight.
P.R.Day and G.G.Holmgren(5): In this work portions of aggregates (size fraction 1 to 2 mm) moistened by adding crushed ice, were precompacted to obtain soil blocks. These blocks were allowed to dry

under room conditions until equilibrium was reached, after which the resistance to crumbling was estimated by manual crumbling of the air-dried blocks (see Table 1).

Albrecht Gerlach(6): Portions of sieved dry loam soil were moistened by mist spraying, and then compacted to form soil briquets. After this precompaction, the desired changes in moisture content were obtained by adding water or by drying under room conditions. The tensile strength of the briquets was then measured by bending tests (see Table 2).

H. Kuipers and B. Kroesbergen(7): Alnkerk silty clay passing through a 10 mm screen, was moistened by the addition of water. After precompaction, the m.c. was changed by adding water or by drying under room conditions. Both the m.c. at precompaction and the m.c. at testing were varied. Testing consisted of measurement of the shear strengths at zero normal load in a torsion shear apparatus (fig. 2).

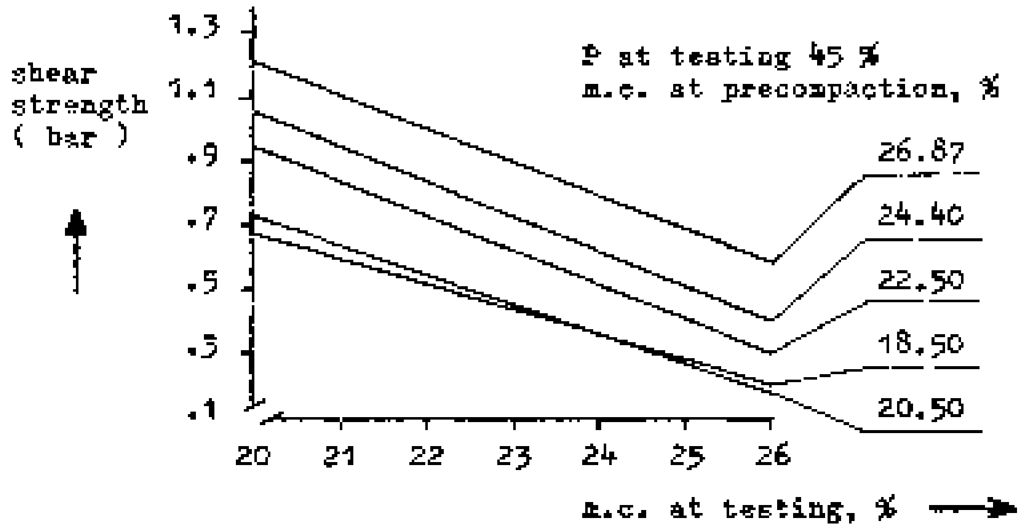

fig. 2

Uni-axial compression tests

a) A given amount of aggregates of Alnkerk silty clay (size fraction 2 to 3.4 mm, m.c. 19%) was divided into two parts, on of which was moistened by the addition of water to obtain a m.c. of 25.6% and the other dried under room conditions to obtain a m.c. of 18.5%. After being precompacted to reach 50% porosity, both soils were dried under room conditions to about 17% m.c. before being subjected to further compaction to determine the uni-axial compaction pressures needed to reach 45% porosity (fig. 3).

b) One part of a given amount of Wageningen silty clay loam which passed a 3 mm screen and had an initial m.c. of 20% was moistened to 27% m.c., precompacted, and dried to 20%. Several degrees of precompaction were applied. Testing consisted of further compaction in uni-axial compaction tests. The second portion was both precompacted and tested at 20% m.c. The necessary changes in m.c. were effected by adding crushed ice or by drying under room conditions. No effect of the m.c. at precompaction was found for any of the degrees of precompaction applied. In these tests the level of compaction pressures was lower than in the tests mentioned under point a.

Table 1

Soil type	M.c. at precompaction	bulk density at testing	soil strength
Silty clay loam	25.5% 16.7	1.22 gms/cc "	weak firm
Clay loam	25.6 19.5	0.85 "	weak very weak

Table 2

M.c. at precompaction	Changes in m.c. between precompaction and testing	m.c. at testing	tensile strength
7%	none	7%	0.25 bar
14%	drying to 7%	7%	1.00
7%	moistening to 14%, then drying to 7%	7%	0.50

Table 3

no.	m.c. at precompaction	m.c. at testing	porosity at testing	σ_f	ε_f
1	27%	19.26%	50.5%	0.89 bar	2.5%
2	27	19.79	50.5	0.87	2.2
3	27	20.12	50.5	0.82	2.5
4	27	19.84	50.5	0.89	2.7
mean	27	19.75	50.5	0.87	2.5
5	20	20.08	50.2	0.47	2.3
6	20	20.07	50.2	0.49	2.0
7	20	20.34	50.2	0.49	2.5
8	20	20.66	50.2	0.41	2.7
mean	20	20.28	50.2	0.47	2.4
9	19	18.91	50.6	0.47	2.2
10	19	18.61	50.6	0.45	2.1
11	19	18.94	50.6	0.52	2.0
12	19	18.98	50.6	0.46	2.2
mean	19	18.86	50.6	0.47	2.1
13	13	18.78	50.4	0.22	4.1
14	13	18.60	50.4	0.21	4.1
15	13	18.49	50.4	0.24	4.0
16	13	18.73	50.4	0.22	4.2
mean	13	18.65	50.4	0.22	4.1

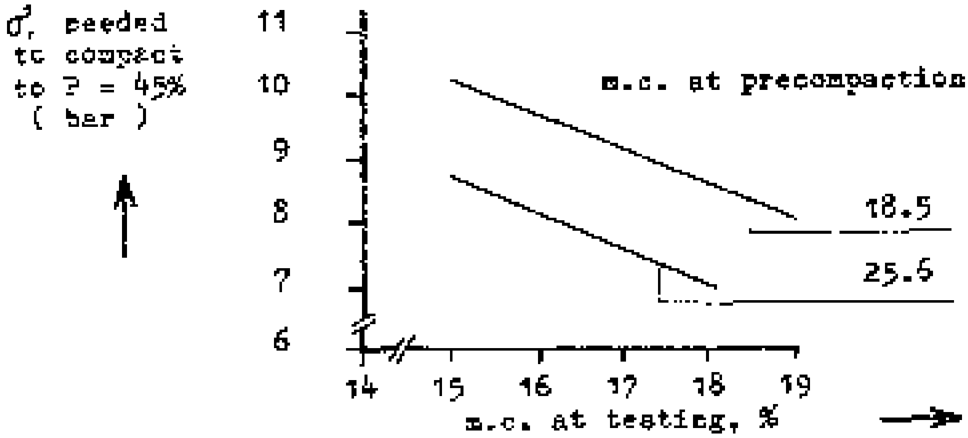

fig. 3

Unconfined compression tests

a) Water was added to Wageningen silty clay loam which passed a 3-mm screen and had an initial m.c. of 10%, to obtain two samples, one having a m.c. of 27% and the other 20%. After both parts had been precompacted, the wettest soil was dried under room conditions to obtain a m.c. of 20%. Testing was performed by trimming soil cylinders and measuring the σ_f and ε_f in them. The results are shown in Table 3(numbers 1-8).

b) A certain amount of Wageningen silty clay loam which passed a 3-mm screen and had an initial m.c. of 13% was divided into two parts, one of which was moistened to 19% with crushed ice, precompacted, and tested. The other part was compacted before being moistened to 19% with ice.(see Table 3, numbers 9-16).

DISCUSSION

The results of these studies indicate that the effect of the m.c. at precompaction is maximal in tests that subject soil samples to a minimum degree of confining pressure, thus in tests in which it is primarily the bonds between soil particles that determine the test results. In tests where the results are dominated by soil bonds, a higher m.c. at precompaction results in greater soil strengths, but in tests including further compaction the opposite seems to hold. Day and Holmgren's measurements on Yolo silty clay loam form an exception to this, and fig.3 shows a range of precompaction moisture contents in which there is no effect at all. It should be noticed that the effect of the precompaction m.c. is hardly distinguishable from the effects inherent in drying and moistening processes occurring between precompaction and testing. According to Gerlach's results, these drying and moistening processes do influence the measurements. The unconfined compression tests indicate that the precompaction m.c. may or may not affect failure strain ε_f .

It is clear that a physical model is needed to provide insight into theinterrelations between precompaction, changes in m.c. and testing. This model should be based on strength factors, for instance: the number of soil particles in a unit of volume, which is the complement of porosity; the distribution of soil particles in space, which is related to pore-size distribution; the volumetric moisture content (cm^3/cm^3); soil-water distribution within the soil; the bonds at points of contact between solid particles not arising from soil moisture tension; and the distribution of these bonds.

In addition the model should include:

1) how the strength factors alter when soil is precompacted,
2) what alterations occur in the strength factors due to drying or wetting,etc., between precompaction and testing, and

3) how the results of uni-axial compression and unconfined compression tests depend on the strength factors.

A contribution to the third problem is given in fig.4, which shows the results of tests on samples having the same total moisture contents (20%), but consisting of parts with various moisture contents.

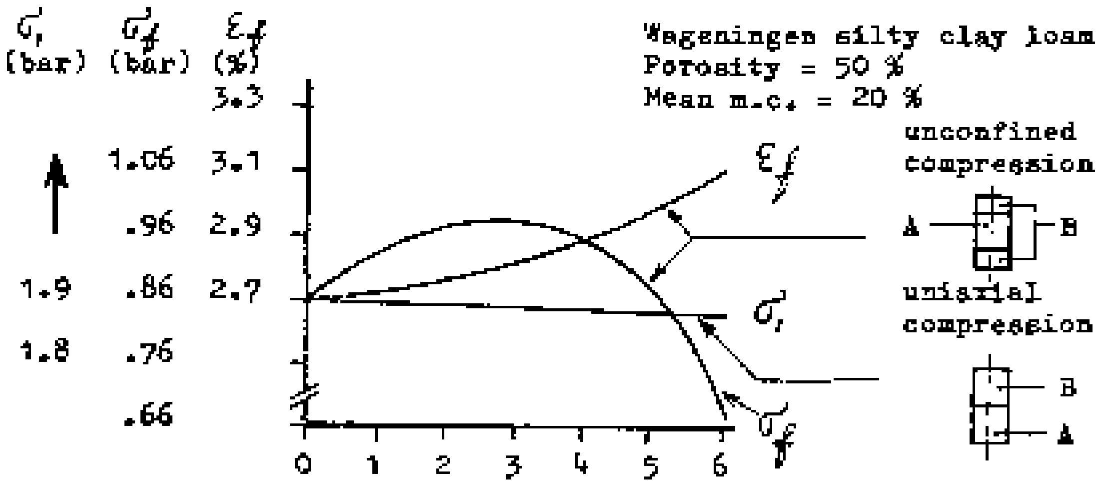

fig. 4

In this figure, σ_1 is the pressure needed to reach 50% porosity in a uni-axial compression test in which the m.c. of the upper half(B) of the sample differs from that of the lower half(A). σ_f and ε_f were obtained in unconfined compression tests on samples whose central parts(A) have moisture contents differing from those of the outer ends (B). It is clear from these findings that unconfined compression tests can be highly susceptible to local differences in m.c. within the sample.

Attempts to elaborate a physical model on the basis of the data in the literature raise many questions which can only be answered by further research.

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Landapplication of liquid manure, fundamental requirements and new techniques

R. Krause, C. Sommer, M. Zach+)

The main objections against the landapplication of liquid manure are odor emissiones and the danger of water pollution. To prevent these dangers should be the aim of each farmer not only because of a general sanitation but because emissiones, leakage and run off are losses of costly nutrients at the same time. To succeed in this effort manure has to be covered with soil immediately after spreading to prevent odor and gaseous losses and to be distributed and mixed very intensively with soil for optimal storage and plant nutrition. Different techniques suitable to combine optimal utilization of nutrients and concerns of environment control are discussed.

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Landapplication of liquid manure, fundamental requirements and new techniques

Introduction

Liquid manure has induced a lot of public discussion and activities in research as well as in legislation. Two main points are discussed:

1. Odor and water pollution, that means environmental control,
2. suitable and optimal application in plant production.

The traditional technique of application has to be adapted to the changing situation in animal and plant production. as well as to the public interest in general sanitation. The more expensive mineral fertilizers become the easier the environmental problems can be solved, especially for animal holdings with no or not enough land to spread the manure, because of the increasing market for manure, and the decreasing pressure to look for possibilities to get rid of this product.

Regarding landapplication of liquid manure the soil has to fulfill three main tasks: To be

1. store, filter and reactor for the liquid and solid phase of manure including all nutrients and other contents,
2. seedbed with optimal plant nutrition and micro climate as well as anchorage,
3. roadway for tractor, tanker and implement.

Functions of the soil

1. The soil as store, filter and reactor:

Odor and water pollution are the main objection to the landapplication of manure. Odor emissions can be reduced comparatively easy by regarding weather, direction of wind, distance of living and recreational areas, time of day, season, spreading equipment and techniques and soon incorporation. Measurements with the olfactometer show that emissions can be prevented immediately and more or less totally independent of the procedure by covering liquid manure with at least a thin layer of soil, but that odor emissions can be reduced already remarkably by a flat curve of the manure stream close to the surface instead of the standard procedure.

More serious is the problem of water pollution and losses especially applying high rates of liquid manure. Trying to find the maximal tolerable application rate we have to separate the hydraulic capacity of the soil (the water holding or field capacity) and the chemic capacity (mainly exchange capacity). Both limits should not be exceeded.

Besides the species of plant, the rotation and some local factors as soil type, soil condition, biological activity and actual fertilizing the degree of leakage of nutrients depends also on the mechanical treatment of the soil. The oxygen supply, corresponding to the pore space, which again mainly depends on mechanic and genetic compaction and loosening and the temperature in the soil that means also the depth of incorporation, influence the store, filter and reactor capacity of soil. But even more responsible for these functions is the actual inner surface of the soil and the chance of liquid manure to meat such free surface - that means sorption complexes - by intensive mixing of liquid manure and soil. The better the distribution of liquid manure in the upper tilled horizon, the smaller is the danger of infiltration and run off.

2. The soil as seedbed

If an individual nutrition of discrete plants is not possible we should try to reach a very constant distribution of fertilizer all over the seedbed to guarantee all the plants the same amount of fertilizer at the same time. There should also be a suitable vertical distribution to make the nutrients available for the roots.

Because the time of application is decisive for the efficiency of fertilizing we should try to applicate as high an amount of the manure as possible just before or during vegetation to prevent high losses during winter time. But this is a problem of storage as well as of timing.

3. Soil as roadway

The trafficability of soil is in close correlation with the time of application and condition of the soil on one side and the size of tanker and the technical equipment including tires on the other side. There are little problems with the landapplication before or during stubble mulch, when the soil is dry and hard. But travelling on surface-spread manure for incorporation in the traditional way causes an increased compaction and slippage, that means damage of soil structure. Deep tracks, especially in spring cause difficulties in seedbedpreparation. Direct injection behind the tanker is an evident improvement, but alternative solutions are discussed in the following.

The technique of incorporation

Three demands can be deduced from the previously said:

1. Covering of liquid manure with soil as soon as possible to prevent odor emissions and run off,
2. even dissemination and intensive mixing of manure and soil to prevent losses by infiltration and surface run off as well as for optimal plant nutrition,
3. landapplication at an optimal time concerning the demand of the plant and regarding the trafficability of the soil.

The most popular implement of the new generation for the landapplication of liquid manure is the tine injector consisting of a beam with several small tines behind the tanker. The manure is pumped through distributor and tubes into the ditch left behind each tine. Normally the odor problem can be solved with this implement but with small tines about 50 cm apart as usually the distribution of liquid manure in the soil is poor (figure 1).

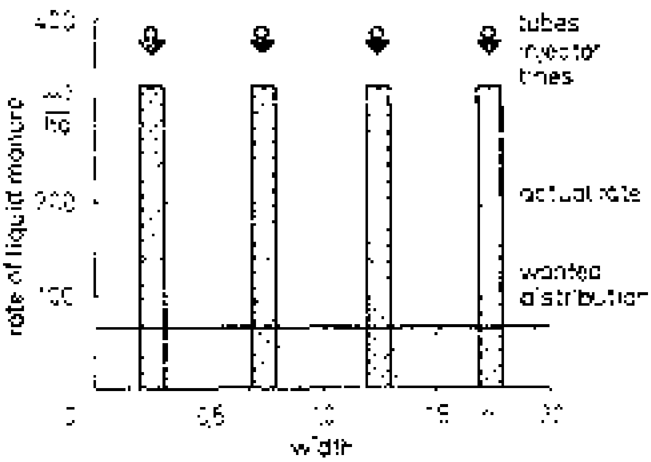

Fig. 1: Theor. pattern of distribution of liquid manure incorporated with a tine injector

To improve the distribution and taking into account the power requirement and the well known progressive increase of soil resistance with depth we have to incorporate manure as shallow as possible and over the total width of the implement. Goose feet shares as used by IMAG Wageningen could be one step in this direction. But in principle all tillage implements furnished with distributors, tubes and possibly splash plates at the ends of the tubes are suitable for the incorporation of manure (figure 2).

An optimum concerning distribution and mixing is the incorporation of manure by active - pto-driven - implements. Injecting liquid manure in the soil flow behind the rotavator total covering as well as a sufficient mixing and vertical distribution are possible (figure 3).

The wanted horizontal distribution depends on the spacing of the tubes and on the pattern of distribution caused by splash plates at the end of each tube (figure 4).

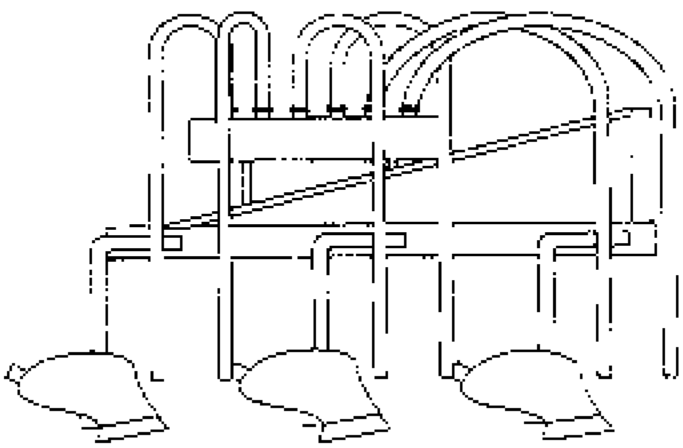

Fig. 2:

Mouldboardplow equiped with distributor, tubes and splash plates

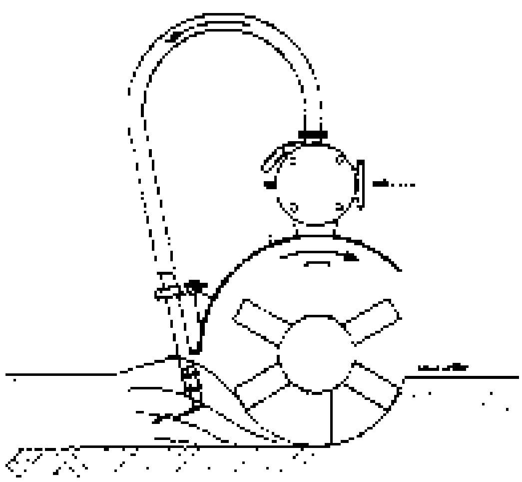

Fig. 3:

Rotavator equiped with distributor tubes and splash plates

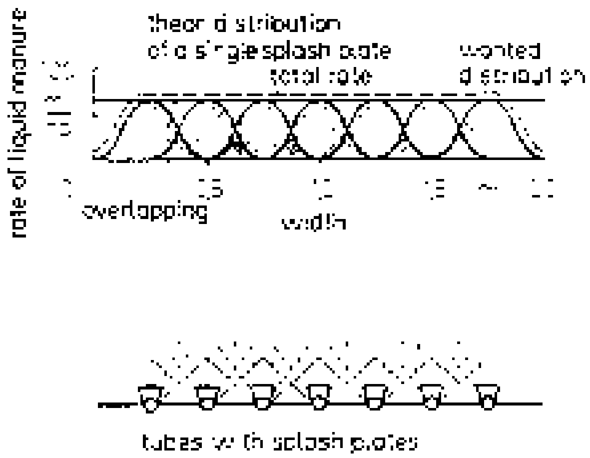

Fig. 4:

Theor. distribution of liquid manure incorporated with a rotavator

Landapplication systems

Three different systems are investigated at the moment:

1. Two tractors going side by side (tandem) one carrying the mounted implement mouldboard or disc plow, rotating plow, chisel plow or rotavator) with the distributor, the second with the trailed tanker, the manure pumped through a connecting hose,

2. the tillage implement is - as known from injectors- mounted on the rear end of the tanker,

3. tractor with mounted implement the manure being supplied through a long, flexible hose from the stationary pipe or from a tanker remaining on the road.

In the tandem system different available tillage implements suitable for the specific soil conditions can be used. The landapplication of manure can be combinated with necessary tillage operations - that means no extra costs for the incorporation - provided the storage capacity and organization are surfficient and suitable. To increase the efficiency of the system several tankers can be operated - depending on the distance from storage to field - in order to supply liquid manure continuously to the tillage implement. Besides the disadvantage of operating two or more tractors at the same time this system seems to be suitable for plane and not too small fields.

A tanker mounted implement requires a heavy tractor. The operation of the implement cannot be watched from the tractor. The efficiency is low at least when the transport has to be performed with the whole unit.

The hose system seems to be restricted to very steep hills fields where the trafficability forbids the operation of heavy tankers and to the application of high rates like in sludge disposal.

Practical field tests with the different systems and high rates of manure prove the superiority of rotavator incorporation concerning a minimum of leakage of nutrients and the highest yields of silo maize. Regarding the practicability and especially the costs of landapplication we have to compare all the mentioned alternatives with their pro and contra keeping in mind the optimal utilization of costly nutrients as well as the public interest in sufficient and high quality food and general sanitation.

The 7th Conference of the International Soil Tillage Research Organization, Sweden, 1976

Problems of straw mixing with heavy cultivators in ploughless tillage systems and consequences for seed bed preparation and seedling emergence.

Dipl.-Ing.agr. Karlheinz Köller, Institute of Agricultural Engineering, University of Hohenheim, Stuttgart, Germany

Abstract:
As more and more farmland is cultivated for small grains and higher yields, the amount of straw produced in that way rises too.
Using that surplus of straw, inserting straw into the soil gets increasing importance. In this connexion better implements and work procedures are demanded. The plough, burying the straw seems to be unsuitable for this purpose. So-called "conservation tillage systems", which are already widely spread in the USA (1) have not been in use in other countries so far.
This is why we have been trying, to use heavy cultivators for mixing straw into the soil (2,3).
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(2) Stroppel, A., Köller, K.: Der Tiefgrubber in der Primärbodenbearbeitung Landtechnik, 29 (1974), 8, p.330-336
(3) Köller, K., Seufert, A.: Vieles spricht für den Tiefgrubber, Mitteilungen der DLG, 90 (1975), 8, p.458-466

In various experiments we have been investigating whether heavy cultivators can be used in ploughless tillage systems. If straw is used as manure every year, it is of high importance to find out which is the best way of mixing straw into the soil.

It is desired that

1) the straw should be distributed completely near the soil surface so that it may rot well and that

2) the following operations for seed bed preparation and sowing should be possible without blocking.

To achieve that

1) the straw should be chopped as short as possible.

2) it should be distributed completely on the soil surface.

3) the stubble should be as short as possible.

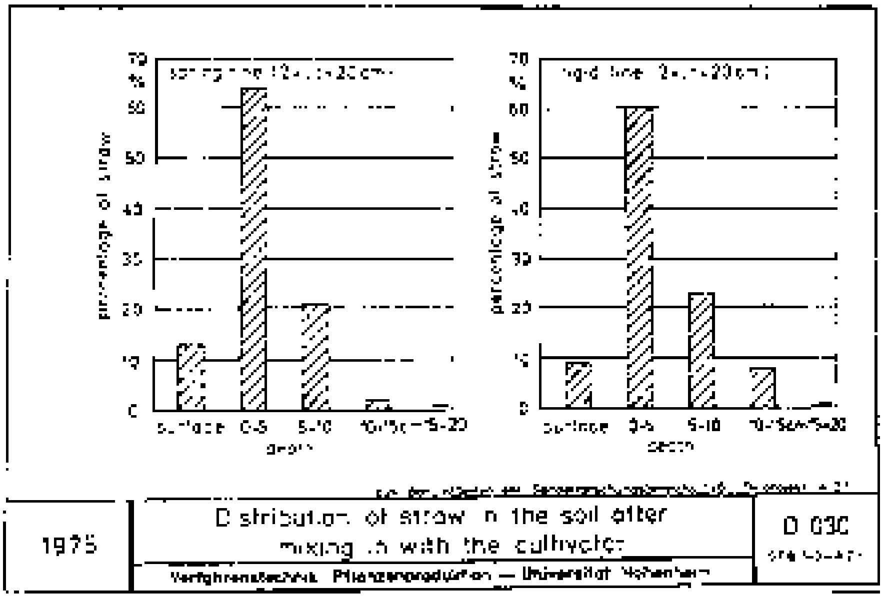
No good incorporation of the straw in the soil can be expected if one of these conditions cannot be fulfilled.

Successful operations with cultivators ar only possible if
1) there is sufficient clearance between cultivator points and the base of the frame (about 75 cm)
2) the distance between the tines in each direction is about 70 cm (Adjustable tines should be provided for flexible spacing of the tines for particular soil and straw conditions).
3) the number and arrangement of tines are chosen in such a way that there is a distance of about 25 cm between the cultivator furrows.
4) supplementary cultivator-mounted implements for ground levelling and further crumbling ar used. (They hardly influence the mixing if there are no driven implements but they facilitate the following passes and operations).
5) the soil is cultivated twice (at right angles) and
6) at different depths: For the first time flat (10-15 cm) for the second time deeper (20-25 cm) with a working speed about 8-10 km/h.

A comparison between a spring tine cultivator and a (spring loaded) rigid tine cultivator may show some results of mixing straw into the soil.

In this experiment 56 dt/ha of chopped straw were inserted into a clay-loam soil. 82 per cent of the chopped straw were shorter, 18 per cent longer than 10 cm.

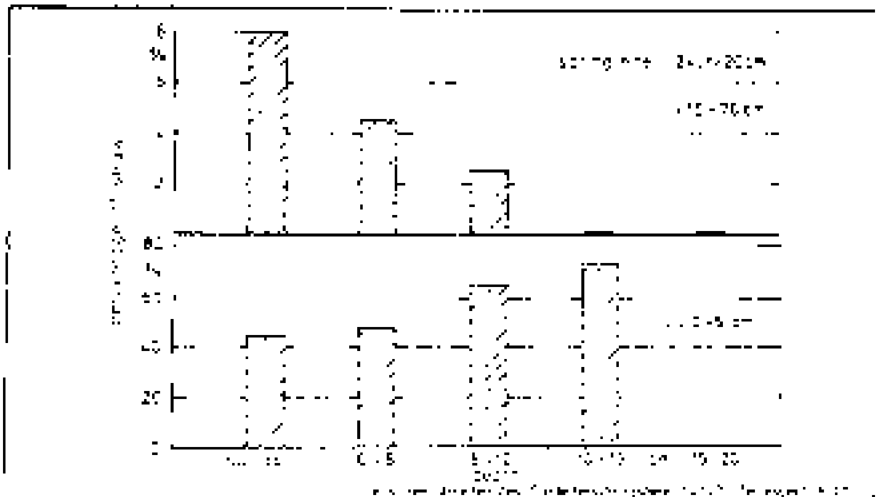
Figure 1



shows that both cultivators placed most of the straw into the layer of 0-5 cm. Also in 5-10 cm both inserted rather the same quantity of straw. It is remarkable that the spring tine cultivator mixes less straw into the depth of 10-15 cm than the rigid tine cultivator. The reason for this is the fact that it is hardly possible to hold spring-tines in constant working depth at changing strength of soil. Although the working depth was adjusted at 20 cm both cultivators did not place the straw into the layer of 15-20 cm. That means that it may be necessary to adjust the cultivator for a depth of 20 cm for mixing the straw in the layer of 15 cm.

Changing strength of soil and different distributions of the lengths of chopped straw are the main reasons why working depth and mixing depth donot correspond. The analysis of the distribution of the lengths of the chopped straw over the mixing horizon explains these relations for the experiment mentioned above. There are rather the same results for both cultivators. With increasing mixing depth the part of straw longer than 10 cm decreases clearly. Straw longer than 15 cm cannot be placed deeper than 10 cm. On the other hand the percentage of straw shorter than 5 cm increases with increasing depth while the straw with the lengths 5-10 cm remains rather constant throughout the whole mixing depth.

Figure 2

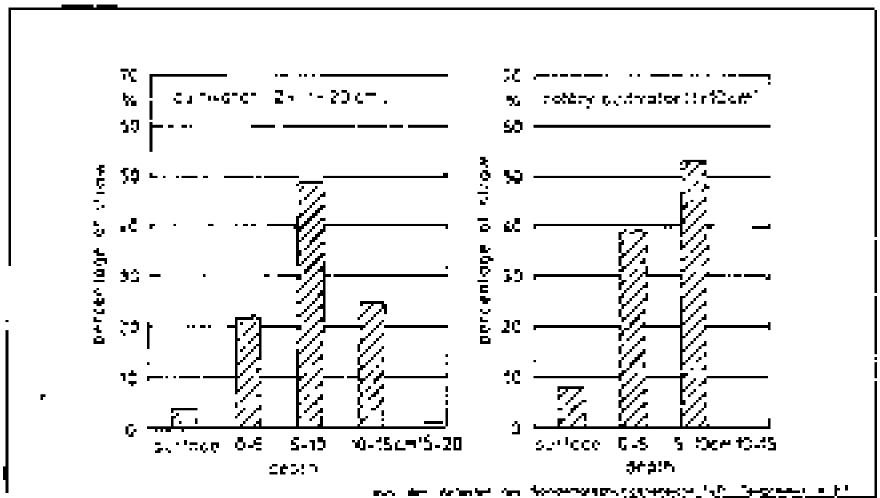


1975	Mixing depth of cultivators depending on the length of chopped straw	D 032

illustrates these statements for the lengths of 0-5 cm and 10-20 cm of chopped straw which is put into the soil by a springtine cultivator.

It can be seen that to achieve a good mixture 80 per cent of the chopped straw should be shorter than 10 cm. To be able to compare the mixing performance of cultivators, other

experiments have been made with the rotary cultivator which is usually considered a very good mixing implement.
The results of the following example are valid for other soil and straw conditions respectively.
In this experiment 50 dt/ha of chopped straw (90 per cent shorter than 5 cm) were mixed into a silty loam by the cultivator and the rotary cultivator.
The working depth for the latter was 10 cm, the cultivator (with spring loaded rigid tines) worked at 10 cm in the first and at 20 cm in the second operation (at rigth angles).
Figure 3



1975 | Distribution of straw in the soil after mixing in with the cultivator and the rotary cultivator | D 029

Verfahrenstechnik Pflanzenproduktion — Universität Hohenheim

shows that both implements place half of the quantity of straw into the depth of 5-10 cm. While some of the straw remained on the surface the rest straw was placed in the layer 0-5 cm by the rotary cultivator while the cultivator inserted the same quantity into the layers of 0-5 cm and 10-15 cm. Because of the high power required for mixing the straw into the depth of 15 cm it is not convenient to use a rotary cultivator.
It should be noted that in the first experiment with a usual distribution of straw lengths most of the straw was placed into the layer of 0-5 cm. In the second experiment with straw chopped shorter than 5 cm most of the straw was mixed into the layer 5-10 cm. It is to be expected that straw chopped still shorter will be mixed even deeper. That means that straw mixing, especially the distribution over the mixing

horizon, can be regulated by the length of chopped straw. The presented experiments show that mixing the straw deeper than 10 cm,which may be necessary if high quantities of straw are to be used and high straw concentration in the sowing depth should be avoided, the cultivator is to be preferred. This statement is supported by results of our rotting experiments that were made with straw of different lengths and different quantities. In these experiments the highest rates of rotting were obtained when the straw was mixed uniformly in the soil layers of 0-12 cm and 0-16 cm. These mixing depths can hardly be achieved by rotary cultivators or disc harrows, especially at high rates of straw and on clay soils. As under these conditions even the skim plough does not work satisfactorily, the cultivator presents a convenient alternative.

A final statement, however, which tines, cultivator points and cultivator mounted implements should be selected cannot be made yet. Nevertheless the cultivator is to be recommended for mixing straw into the soil. Because of the danger of blocking the use of cultivators on sand soils is more limited than on loam and clay soils.Further advantages of the use of the straw - inserting cultivator are the reduction of energy and labour requirements and good control of perennial weeds combined with deep tillage, which may substitute the plough eventually. In this case cultivating twice at different working depths seems to be necessary especially to reduce the amount of straw that remains on the soil surface. Only in this case the use of conventional implements for seed bed preparation and sowing is possible without the danger of blocking. So an important condition of using cultivators successfully is fulfilled and the plough may be substituted. If this condition cannot be realized , special implements like combinations of rotary cultivators and seed drills or disc drills are necessary for the field cultivation. According to this statement the seedling emergence of following crops and the development of weed are influenced by the used cultivator operation. One operation of the cultivator mixing straw simultaneously is mostly not sufficient to produce good conditions for seed bed preparation and sowing. Remaining straw on the soil surface causes blocking of the implements. Affected by these obstructions and by the high concentration of straw in the sowing depth a reduced seedling emergence is to be expected.

A much better result is achieved if two operations follow each other after an interval of 3-5 weeks. In this case there is a good seedling emergence and crops are nealy free of weed and of plants of the previous crop.

Although the cultivator cannot be recommended as an implement to substitute the plough generally, the experiments carried out up to now show that is can replace the plough occasionally without diminishing yield if a good straw mixing into the soil is obtained.

Possible lower yield when using the cultivator can be compensated by reducing cultivation costs with regard to comparable plough systems.

Lower labour requirements of about 30-50 per cent and lower fuel consumption of the same rate considerably affect these lower cost. These dates are in correspondance with the experiences of farmes who have substituted the plough by cultivators for some years.

The 7th Conference of the International Soil Tillage Research Organisation, Sweden, 1976.

AN APPROACH TO TILLAGE RESEARCH IN THE HUMID TROPICS OF WEST AFRICA.

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ABSTRACT.

Soil erosion, high soil temperature, frequent drought stress and decline in the organic matter content of the soil are some of the problems that are when large-scale mechanized farming replaces traditional shifting cultivation in the humid tropics of West Africa. Mulch farming with no-tillage techniques has been shown to decrease runoff and soil loss, improve soil-moisture and soil-temperature regimes, and maintain soil organic matter content. However, no-tillage techniques may not be applicable for all soils and for all agro-ecological environments. This system can be made more versatile by appropriate research to develop planting tools for small-scale farmers, economical methods of weed control, and methods for applying fertilizer and maintaining mulch material on the soil surface.

1. INTRODUCTION

Transfer of technology from North America and Europe to subsistence-level farmers of the humid tropics, though occasionally successful (Sanchez and Buol, 1975), is impossible for most small-scale farmers who cultivate soils of low inherent fertility in the forest region of West Africa. Because a majority of these soils are susceptible to serious degradation problems, farmers throughout the tropics have evolved a method of rejuvenating soil fertility that includes a long forest-fallow periods. This method is called "shifting cultivation" (Greenland, 1975). With this method, the chemical nutrients removed are replenished by nutrient recycling, soil structure is maintained by the presence of continuous cover, and the buildup of weeds, pests and diseases is checked through forest-fallow rotation. The system breaks down under the pressure of population however.

Large-scale forest removal and subsequent soil exposure by mechanical cultivation results in accelerated soil erosion, reduced infiltration rate and water retention capacity of the soil and decreased organic matter content and nutrient holding capacity. As a result, soil productivity declines rapidly. The erosion control by contours, terraces and other mechanical means has both technical and social limitations. Once the shallow surface horizon is eroded, it is extremely difficult to replenish soil fertility. Seed bed preparation methods are key factor constraining the development of agriculture in this region.

II. <u>FACTORS INFLUENCING TILLAGE RESEARCH</u>

<u>Soil Erosion:</u>

(i) Soil erosion is one of the major limiting factors to introduce continuous cultivation, its control is the first priority. The potential for soil erosion in the humid tropics is high because of high climatic erosivity and highly erodable characteristics of many soils. Annual soil losses from plowed bare ground for four years after forest removal are shown in Table 1. The amount of soil lost increases for about two years after clearing, and then decreases due to increased gravel concentration in the surface layer.

(ii) <u>Soil Temperature:</u>

In the tropics, the growing season follows a long period of hot and dry weather just the opposite of the pattern in the temperate zone. In the seedling stage, the temperature of bare soil can reach as high as 45°C at 5 cm depth and 50°C near the

Table 1. Soil losses from plowed bare soil (tons/ha)

Slope %	Years After Forest Removal			
	1	2	3	4
1	5	11	9	10
5	43	156	134	148
10	59	233	136	76
15	116	229	96	82

surface. Maize and soybean seedlings, especially suffer from high soil temperature (Table 2).

Table 2. Soil temperature at 5 cm in the interrow zone under unmulched maize 3 weeks after planting (°C).

Distance from the row (cm).	Time			
	08.00	11.00	15.00	17.00
0	25.0	30.6	34.6	35.0
10	25.1	21.0	35.6	36.0
15	25.0	29.8	38.5	37.0
25	24.7	29.8	40.8	38.5
37.5	24.6	33.4	44.1	39.0

(iii) <u>Drought Stress:</u>

Strongly interacting with high soil temperature is the moisture stress under upland rainfed agriculture. The available water holding capacity of the sandy surface horizon is low, while the root penetration into the sub-soil is restricted because of the gravel layer (Babalola and Lal, 1976).

(iv) Organic matter:

The organic matter content of the soil declines rapidly after forest is cleared. Even plowing the crop residue under does not maintain the organic matter content of the soil. For example, the rate of decline of soil organic matter content in an alfisol in Nigeria where maize residue was plowed in was 0.11 percent per month during the first year and 0.02 percent during the second (Lal, 1975). The decline in soil organic matter content encourages leaching of cations such as Ca^{++}, Mg^{++} and K^{+} and increases soil acidity.

(v) Socio-economic problems:

The technology required and the machinery needed for tillage may neither be available to the small farmers nor it is adaptable to his level of education and normal scale of operations (Greenland 1975).

3. MULCH FARMING:

A solution to most of these problems lies in frequent and adequate use of crop residue as "mulch." The present system of shifting cultivation can also be improved, rather than replaced, by addition of simple, but low in-put and effective technology. Recent studies indicate that mulching at the rate of 4 to 6 tons/ha of straw effectively eliminates runoff and soil loss risks even on 15-percent slopes (Lal, 1975). Soil temperatures under mulch are in the tolerable range (Table 3), and higher level of soil organic matter content is maintained (Juo and Lal, 1976). Soil organic carbon content with maize residue used as mulch was maintained at 1.6% three years after forest removal compared to 1.0% in the soil of unmulched plots. Consequently, the pH of the soil in the mulched plots was 5.5 compared to 5.0 for the soil in the unmulched plots.

Table 3. Mulching influence on soil temperature at 5 cm depth under maize 3 weeks after planting (°C).

Distance from the row (cm).	Time 08.00	11.00	15.00	17.00
0	25.2	27.2	31.6	31.5
10	25.2	28.6	33.6	32.2
15	25.0	27.2	34.3	33.0
25	25.2	27.2	33.8	33.2
37.5	25.2	29.6	36.6	34.6

There is a real need to make mulch farming techniques practical under diverse conditions, including the use of herbicides for no-tillage techniques.

4. NO-TILL FARMING IN THE HUMID TROPICS:

No-tillage farming is more suited to the humid tropics than to temperate regions. While slow soil warming and poor drainage with no-tillage are disadvantages of no-tillage farming in temperate regions, these are advantageous in the tropics. Soil erosion, from five-hectare uncontoured watershed under no-till maize was significantly lower than that from a watershed with regular anti-erosive contours and waterways but planted to maize with conventional seed-bed preparation methods. (Table 4).

Table 4. No-till effects on runoff and soil loss under maize from 5-ha watershed.

Replication	Runoff (mm) No-till	Runoff (mm) Plowed	Soil loss (tons/ha) No-till	Soil loss (tons/ha) Plowed
1	94	187	2.3	4.3
2	84	230	1.8	5.2
3	81	203	1.6	4.9
4	79	205	1.8	5.2
5	82	358	2.0	9.3
6	103	294	1.9	8.6
7	94	284	1.8	8.6
8	92	258	1.7	5.8
Mean	89	252	1.9	6.5

High biological activity of earthworms (Hyperiodrilus Africanus) under mulch keeps the soil in no-till plots porous and the bulk density low (Fig. 1). Consequently, crop roots penetrate more deeply in no-till plots. Soil temperatures in no-till plots are significantly lower (Table 5) and the soil moisture regime is better than in plowed plots.

Table 5. Soil temperature regime under no-till and plowed maize at 5 cm depth (°C) (30/4/1974).

Treatment	Time			
	08.00	11.00	15.00	17.00
Plowed	26.5	33.2	36.8	36.3
No-till	27.3	28.0	29.2	29.6

The composition of soil air is significantly influenced by plowing and no-tillage. Because the crusting problem is minimal under mulch in the no-tillage plots, there is free exchange of gases between the soil and atmosphere. Consequently the soil air in no-till plots has higher O_2 and lower CO_2 concentrations than the soil air in plowed plots (Table 6).

Table 6. Tillage effects on the composition of soil air under maize*

Treatment	O_2 %	CO_2 %
Plowed	15.8	2.94
No-till	20.6	0.34

*The analysis was done by Dr. J. Burford of Letcombe Lab., U. K.

No-tillage effects on the grain yield of various crops in the African tropics has not bee extensively reported. However, the little data that are available indicate that yields equivalent to those produced by conventional plowing can be obtained with no-till systems of soil management (Table 7). Crop performance with no-tillage depends on various soil and environmental factors.

Table 7. No-tillage on minimum tillage effects on crop yield in the tropics of Africa.

	No-till Yield (% of Plowed)	Year	Location	Country	Source
Maize	233	1961	Kumasi	Ghana	*Kannegieter (1969)
Maize	77	1967-68	Kongwa	Tanzania	Macartney et al (1971)
Maize	98	1975	Ilora	Nigeria	
Cowpea	117	1974	Ilora	Nigeria	
Maize	105	1975	Ikenne	Nigeria	
Cowpea	131	1974	Ikenne	Nigeria	
Maize	72	1974	Monrovia	Liberia	
Maize	215	1973	Monrovia	Liberia	
Rice	152	1973	Monrovia	Liberia	
Maize	78	1974	Obubra	Nigeria	
Maize	129	1975	Ibadan	Nigeria	
Sorghum	99.5	1974	Gaborone	Botswana	Whiteman (1974)
Maize	97	1973	Kampala	Uganda	Olum and Henderlong (1975)

*Use of Pueraria with no-till treatments.

5. RESEARCH NEEDS:

The performance of no-tillage techniques depend on many factors and the adaptation of this system to diverse soil and climatic demands research along the following lines:

(i) No-till Planters for the Small-Scale Farmer: There is a real need to develop appropriate tools for planting through mulch.

(ii) Weed control: Weed control can be a seriously limiting factor in the adaptation of no-tillage system in the tropics. Rhizomatus weeds such as *Imprata cylindrica* and *Talinum triangulare* may pose serious problems. The effectiveness of cheap ultra-low-volume (ULV) sprayers need to be investigated and appropriate technology developed.

(iii) Fertilizer needs: No-tillage systems may require additional nitrogen, at least during the early years of adoption of this technique. There is a need to investigate the rate and method of placement of fertilizer and develop appropriate technology.

(iv) Cover Crops: The effectiveness of no-tillage techniques can be significantly improved by rotation with appropriate cover crops every three or four years. In addition to weed, insect and disease control, these cover crops can help improve the organic matter content and nitrogen status of the soil and provide mulching material. Some of the promising cover crops include *Stylosanthes gracilis*, *Pueraria phaseoloides* and *centrosema*.

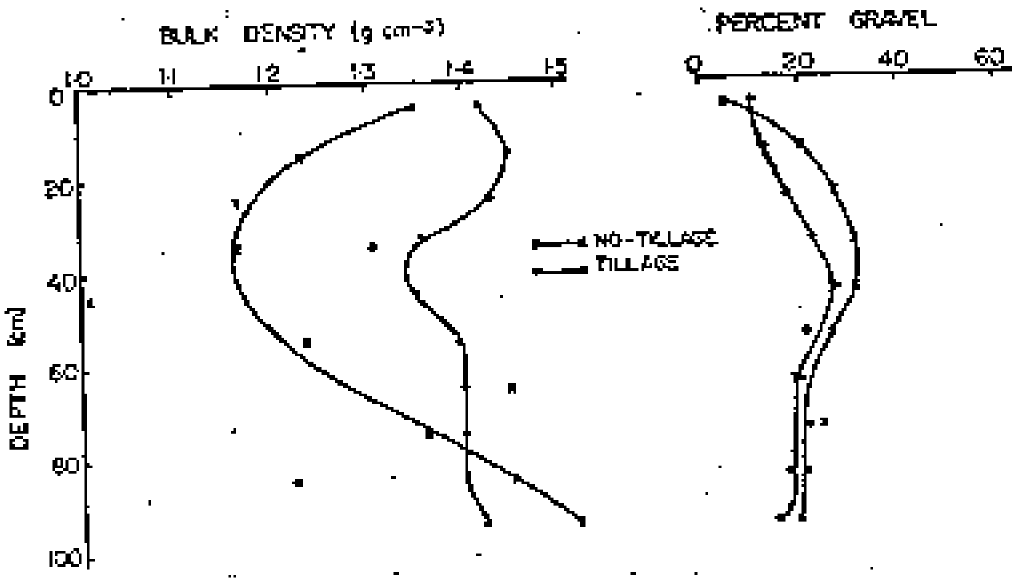

Fig. 1. The effects of five years of no-till and conventional plowing on soil bulk density profile.

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The 9th Conference of the International Soil Tillage Research Organization, [illegible], 1982.

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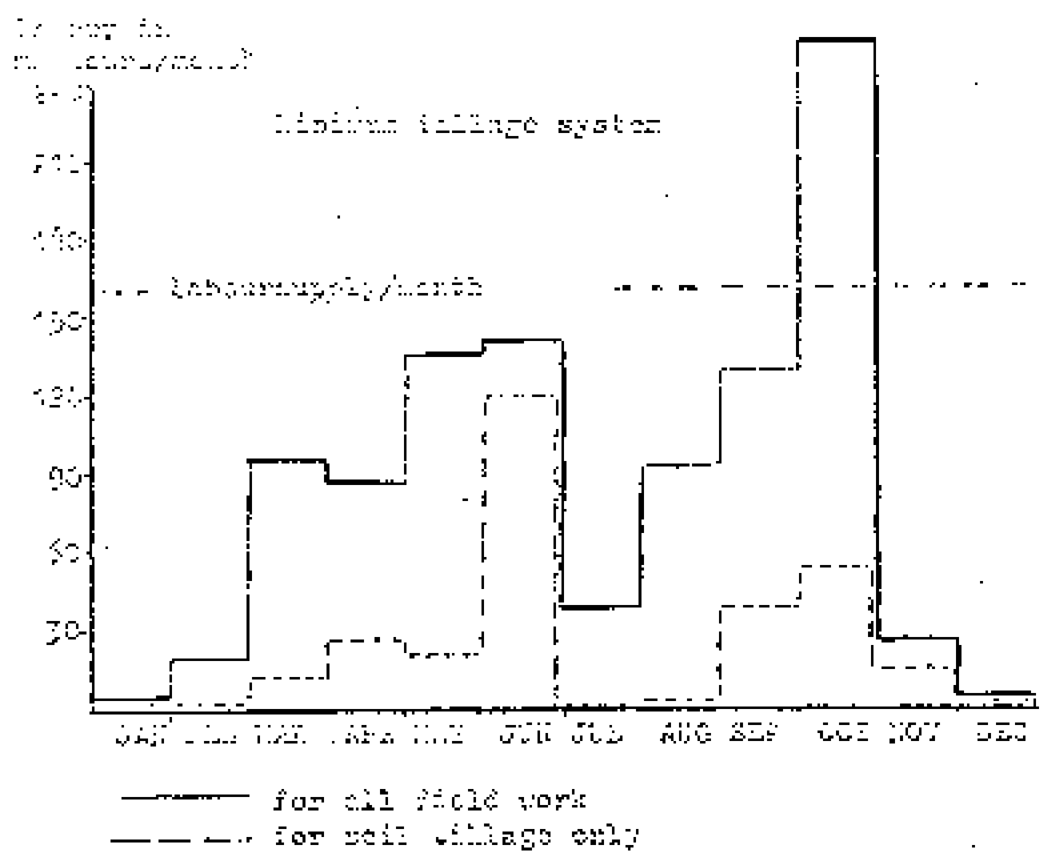
ABSTRACT.

With a minimum cultivation technique on blowing sensitive soils in the north-eastern part of the Netherlands a 4-year crop rotation of potatoes-sugarbeet-potatoes-cereal is practised. Rye is used as a cover crop to prevent blowing (LUMKES & TE VELDE, 1974, 1975).
Each four years soil sterilization in this case is ordered by law (HYINK, 1972). It is realized by a deep soil tillage. Under the circumstances of this research only a flat one pass soil tillage in the periods in between the four years is necessary. It saves time in a peakperiod.

INTRODUCTION.

In the Netherlands approx. 10% of the 700.000 hectare of arable land is susceptible to wind-erosion. Sand soils with an organic matter content of less than 7% and reworked peaty podzol soils with a content of less than 15% are classified as blowing soils (SPOOR[illegible], 1971).
In the north-eastern part of the Netherlands this soil type is in use for an intensive rotation of root-crops. This includes each two years potatoes (for the starchfactories) and almost each four years- or even more often - sugarbeet. It results in a rotation of potatoes-sugarbeet-potatoes-cereals or maize-potatoes-sugarbeet and so on.
With this frequency of potato growing each four years soil sterilization to control potato eelworm (Heterodera rostochiensis) is ordered by law (HYINK, 1972). It is carried out by the injection of chemicals on furrow-depth, which means a soil-tillage up to this depth.
Especially sugarbeet in the described situation often is introduced on a for this crop marginal soil. To prevent soil from blowing and to minimize the growing risk of crops such as sugarbeet, potatoes, e.g., a system of minimum cultivation has been developed in which rye can be used as a cover crop. (LUMKES & TE VELDE, 1974, 1975). Sugarbeet, maize and some other crops in this system are drilled in the rye mulch without any seedbed-preparation in spring. The rye which is drilled in autumn, is killed by a chemical before the drilling time of the crops mentioned. The system includes that in this case the seedbed for the next main crop already is made in autumn.
With potatoes, rye as a cover crop is in use in a different way. Before planting potatoes the rye is not killed, but just thinned out with a spring tine cultivator to limit water

[illegible] covered by the rye [illegible]. In one or two passes ([illegible]) [illegible] half of the rye is mixed with the soil and loose soil, [illegible] potato ridges are formed. After potato-planting the rye is allowed to grow [illegible] again to provide continuing blowing protection until [illegible]. 50% of the tubers planted have emerged. Then the rye is killed.



Labourfilm of a 40 ha farm on reworked peat-soil

18,2	ha	starch-potatoes	50%
1,8	ha	seed-potatoes	
10	ha	winterwheat	25%
10	ha	sugarbeet	25%

Figure 1 illustrates the labour needed pro man for a 40 hectare farm size with this rotation (GEVAAL, 1976). The described system lowers the labour-peak in spring, but not that in autumn. In 1975 a five years research is finished, in which in this intensive crop rotation with each two years potatoes and each four years sugarbeet is compared:
each year ploughing;
each two years ploughing;
each four years ploughing;
each four years deep cultivating (fixed tine cultivator);
no deep tillage for five years.
The results are presented in this paper.

DESCRIPTION OF THE TRIAL.

a. The soil.

The trial is carried out on a [illegible] hectare farm, with [illegible] sand soil and a very intensive rotation of arable crops. The trial is part of a [illegible]. The soil of this [illegible] reclaimed in 19[illegible] [illegible] [illegible] [illegible] about [illegible] percent of the [illegible] and the [illegible] (M-figure) around [illegible] (U-figure) is about 7%.
The average water table is rather deep, mostly [illegible] below surface. In dry years this low water table and the [illegible] content can result in reducing of the yields of the crops.

b. The trial.

The trial started autumn 1970. In 1971 silage maize is grown, in 1972 potatoes, in 1973 sugarbeet, in 1974 potatoes and in 1975 rye as main crop, so each year only one crop is grown. Rye as a cover crop, to control wind erosion, is drilled each autumn, except in 1974/75.
In four replications and on a practical scale, with e.g. the methods and implements of the farmer, the trial includes the comparison of ploughing each year, each two years, each four years, cultivating with a tined tine cultivator each four years, and no deep tillage since five years. Autumn 1974 the trial is split into two parts. On the half of the field each year and each two years ploughing versus no deep tillage since 1970 is continued. On the other half, each year, each two years and each four years ploughing or deep cultivating is carried out according to the original scheme. When no deep tillage was carried out after harvest, mostly in one pass a flat tillage operation was carried out to till the soil surface and to incorporate the broadcasted rye. Always the crop residues, such as leaves and stems of sugarbeet, straw, are mixed with the soil. In this way the farmer tries to stabilize the organic matter content of the soil. The rye as cover crop also helps in this way. So returned to the soil is in a year with potatoes about 3000 kg/ha organic material, with sugarbeet 6000 kg and with a cereal crop 3000kg, this results in average in 4000 kg/ha/year.

RESULTS.

The results of the described research are controlled in terms of labour reducing, physical yields of the crops, weeds, soil physical and soil chemical aspects.
The effect in labour reducing is clear. When for soil tillage only one pass over the field is made after harvest and this takes place with a rather high speed, which is possible when the tillage only includes a flat one, the saving in time in a peakperiod is important.
The results in yield of the crop, as measured since 1972, are summarised in figure 2. In spite of the four replications there was no significant difference in yield between the subjects (P 0.05), also not in quality or other aspects. The positive effect of deep cultivating for the first time since 1970 in

Figure 2. [illegible]

subjects	1972 potatoes	1973 sugarbeet	sugar	1974 potatoes	1975 winterrye	change in tillage	1975 winterrye
A each 4 years ploughing	102	96	[illegible]	102	93	A ploughed autumn 1974	96
B each 2 years ploughing	106	97	97	102	101	B ploughed autumn 1974	95
C each year ploughing	100	[illegible]	100	100	100	C ploughed autumn 1974	100
D each 4 years cultivating	106	97	94	120	96	D cultivated autumn 1974	103

1972, potatoes , variety Prominent 100 = [illegible] kg/ha
1973, sugarbeet, variety [illegible] 100 = 45.000 kg/ha
1974, potatoes , variety Prominent 100 = 53.000 kg/ha
1975, winterrye, variety [illegible] 100 = [illegible] kg/ha
1975, after change in tillage 100 = [illegible] kg/ha

autumn 1974 (see figure 2) however, is significant better as some other subjects, such as each year ploughing.
Normally on this type of soils weeds may produce a problem. Specially couch grass (Agropyron repens) can be mentioned in this case. On the trial field there was not much couch grass and in the course of the years not any difference at all between the subjects was found and not one weed created a problem.
Soil-physical research is carried out during the trialperiod. The results with samples, taken in August 1975 after the rye-harvest, are given in figure 3. It shows the water/air content at pF 2.0 (weight percents) versus the percentage of pore spaces, for the layers 12-17 cm and 22-27 cm below surface. According to previous results the variability in and between the subjects for the layers up to 12-17 cm is very small. In the layers 22-27 cm and 32-37 cm - surface the natural variability is much greater. As is shown in figure 4 for the layer 22-27 cm below surface there is some difference between the subjects. Intensive ploughing however seems not to be as positive on this soil-type as assumed.
The soil-chemical research is finished by an intensive sampling autumn 1975. No important differences were found between the subjects. The results in N-mineral content are given in figure 4. As is shown in this graph there are differences in content between the subjects pro layer. It contains however no significant difference between in reality different subjects.
Based on this research it seems justifiable to conclude that with the intensive crop rotation as mentioned and on the soil type as described a normally each year carried out deep soil tillage can be restricted to once in the four years.

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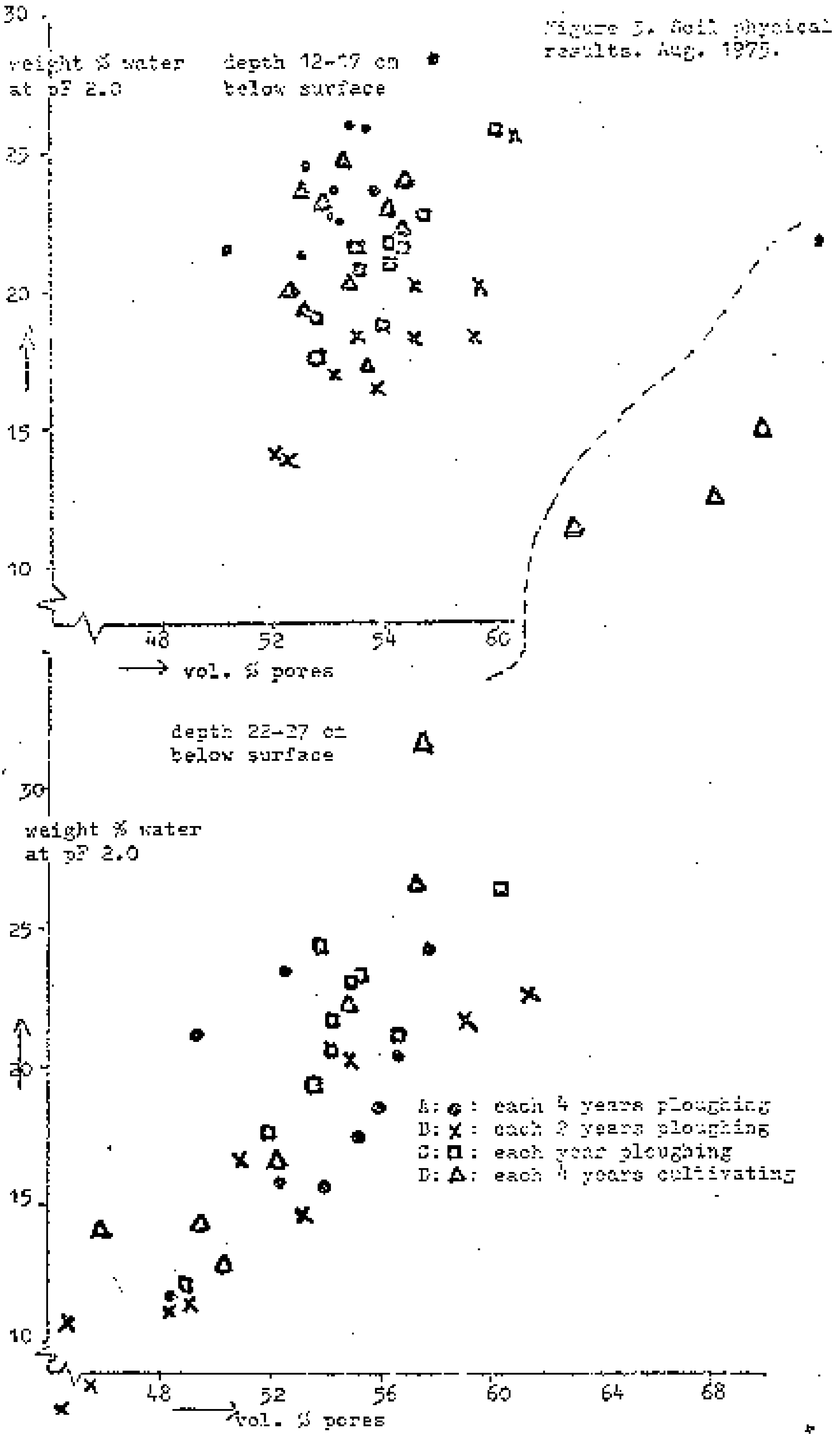
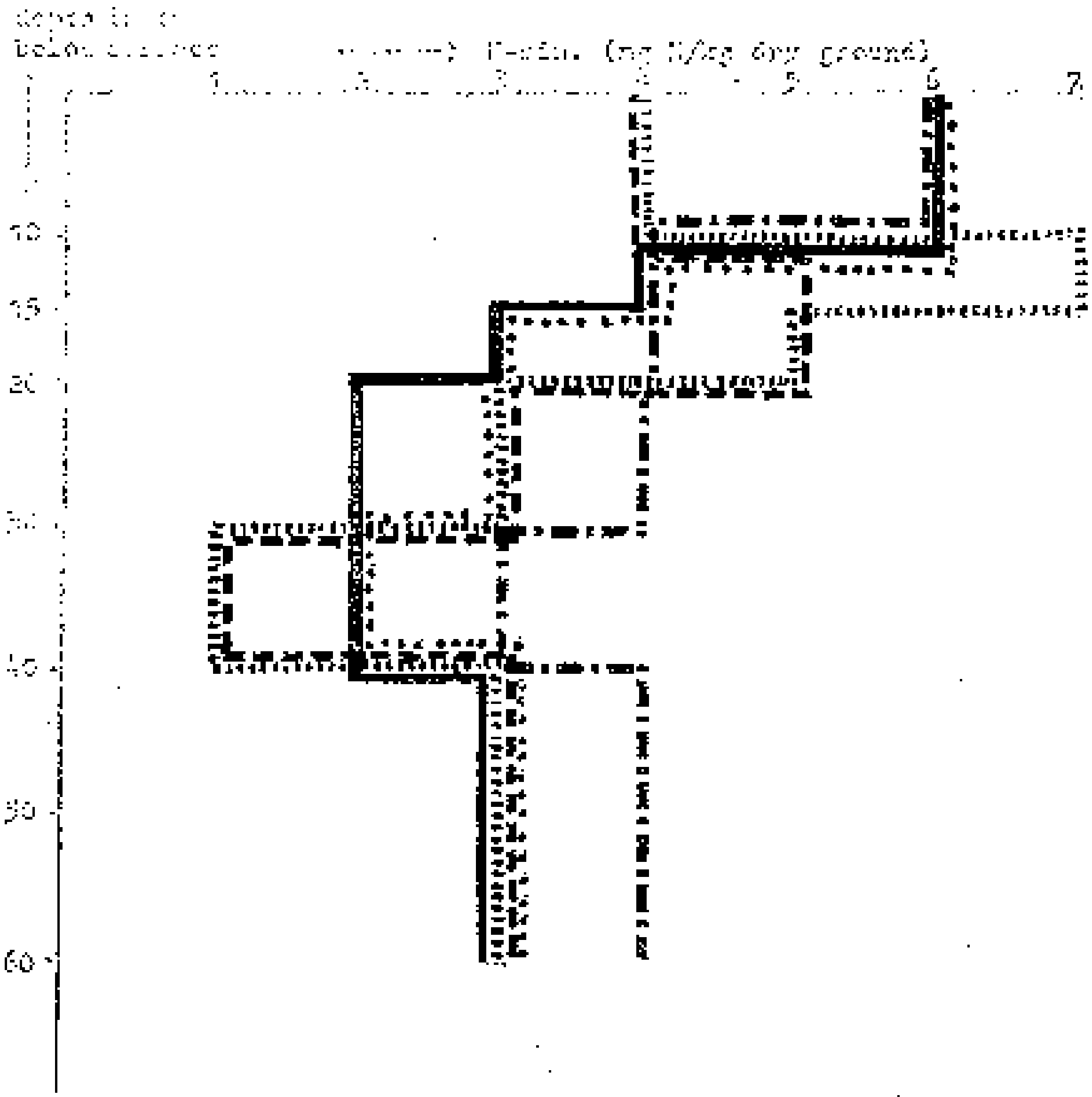
Figure 5. Soil physical results. Aug. 1975.



[illegible], [illegible] [illegible] Informatie [illegible] [illegible] [illegible]
[illegible] [illegible] [illegible] [illegible] (19[illegible]).
[illegible] [illegible] kwerbeun op [illegible] [illegible] [illegible]
[illegible] [illegible] [illegible] voor de [illegible], 197[illegible].
[illegible] [illegible] and [illegible] to [illegible] Protection of wind erosion
([illegible]) cultivation technique on soils susceptible to
[illegible] [illegible] sugarbeet, potatoes etc. [illegible]
[illegible] [illegible] British Weed Control Conference,
[illegible]

Figure [illegible] [illegible] [illegible] 3 Aug. 197[illegible] after different
[illegible] [illegible] since 197[illegible].



A each 4 years ploughing

B each 2 years ploughing

C each year ploughing

D each 4 years cultivating

Dc cultivated autumn 1974

The 7th Conference of the International Soil Tillage Research Organization, Sweden, 1976.

AGRONOMIC ASPECTS OF RESIDUAL EFFECT OF DEEP CULTIVATION FOR MAIN FIELD CROPS

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ABSTRACT

On the prevailing soil types of the main agricultural regions of Croatia, the residual effect of deep tillage was determined by the yield increase of the principal field crops (maize, wheat, sugar beet and lucerne).

As the residual effect of deep tillage is changeable and unreliable, and generally less expressed than the residual effect of fertilizing, the decision should be brought for each particular case whether this phenomenon should be made use of in reducing the depth of the basic operation or even temporary no-tillage, provided the achieved productivity is not decreased.

INTRODUCTION INTO THE PROBLEM

Deep tillage (over 30 cm), either by turning or deep loosening of the soil mass, brings about considerable changes, primarily in the pedophysical complex and layering. At the same time, deep tillage requires great energy consumption, increasing with the operation depth. Deep tillage is generally applied on texturally heavier soils of unfavourable stratigraphy, either as an ameliorative measure or to satisfy special requirements of crops with deep roots.

Considerable changes in the pedosphere, due to deep tillage, are manifested in the phenomenon known as the <u>residual effect of deep tillage</u>, which is evaluated by the yield increase of the crops grown, as compared to the tillage to the usual depth.

As tillage is accompanied by fertilizing (mineral or organic) in the agrotechnical practice, the fertilizer doses being in positive relation to the mass of the cultivated soil, the residual effect of deep tillage implies also the residual effect of fertilizing, and also their interaction.

The residual effect of deep tillage depends on the following factors: soil type, climate, depth and quality of tillage, fertilizing and specific crop reaction. This reflects its complexity and dynamics.

The possibility of utilizing this phenomenon should be viewed from the aspect of reducing the basic tillage depth, but simultaneously ensuring a stable and high productivity in plant production.

Our findings refer to the agronomic aspects of the residual effect of deep tillage for the principal field crops in the main agricultural regions of Croatia.

LITERATURE RELATING TO THE PROBLEM

In professional literature, the problem in question is treated in a rather limited and mainly general way. More data on the residual effect of deep tillage are found in Italy. Thus, BALDONI (1965) obtained increased yields of wheat and sugar beet at normal ploughing of a heavy soil, which followed deep ploughing at 65 cm.

In this country, DAMZGIĆ et al. (1964, 1967 and 1968) determined the residual effect of deep tillage on chernozem for wheat and maize. It should be mentioned that there was a parallel residual effect of fertilizing and ploughing in of the lucerne field.

Also on chernozem, STAMACEV (1965) obtained the residual effect of deep tillage and fertilizing on sugar beet, particularly in the system of "creating a homogeneous fertile deep plough-layer".

STOJANOVIĆ, MILADINOVIĆ and DJURIĆ (1964) recorded the residual effect of deep ploughing and mineral fertilizing upon the maize yield on smonitza and pseudogley soils in Serbia.

INVESTIGATION RESULTS AND DISCUSSION

On the prevailing soil types of the main agricultural regions of Croatia the residual effect of deep tillage was studied, in 17 trials on 10 locations, from 1958 to 1974. The residual effect was assessed by the yields of the principal field crops: maize, wheat, sugar beet and lucerne.

The tillage depth went down to 100 cm of extremely deep ploughing and 100 x 100 cm deep loosening (subsoiling), but mostly between the ploughing at 50 to 60 cm. Parallel to the different ploughing depths, the doses of mineral fertilizers were graded from 267 to 1080 kg/ha NPK nutrients.

It should be pointed out that the depths over 40 cm had an ameliorative purpose on secondary pseudogley on carbonate loess and on oligotrophic pseudogley.

The most important investigation results (variationally statistically evaluated) are presented in Table 1.

When summing up the obtained results it becomes evident that in 11 out of all 17 trials deep tillage had a residual effect, while mineral fertilizing in 15, in most of which on deep tillage. The residual effect of deep tillage on the investigated soil types in different years varied according to the operation depth, weather conditions and specific reactions of the crops, but on the average the residual effect of fertilizing was more marked than that of tillage, generally with the highest fertilizer doses.

Our results basically agree with those obtained by other investigators in other agricultural regions of Yugoslavia and in other countries.

TABLE 1 - RESULTS OF INVESTIGATIONS INTO THE RESIDUAL EFFECT OF DEEP TILLAGE

AGRICULTURAL REGION	SOIL TYPE	CLIMATE OF THE REGION	PLOUGHING DEPTHS AND MINERAL FERTILIZER DOSES AT THE START OF INVESTIGATIONS	YEAR WHEN BASIC TILLAGE AND FERTILIZING WERE CARRIED OUT AND LOCATIONS	YEAR OF TESTING THE RESIDUAL EFFECT AND TEST-CROPS	DID THE RESIDUAL EFFECT OF TILLAGE APPEAR AND THE MAXIMUM YIELD SURPLUS, q/ha	DID THE RESIDUAL EFFECT OF FERTILIZING APPEAR AND THE MAXIMUM YIELD SURPLUS, q/ha
1	2	3	4	5	6	7	8
Eastern Croatia (Slavonia)	Brown soil on carbonate loess, highly anthropogenized	Semi-humid	45 cm unfertilized	1958. Osijek	1960. winter wheat	yes 9.45 q/ha of grain, ploughing at 45 cm without fertilizing	-
"	"	"	47 cm, 54 cm, 267, 534 and 801 kg NPK/ha	1963. Osijek	1965. winter wheat	yes 10.73 q/ha, ploughing at 47 cm	yes 10.54 q/ha, 801 kg/ha NPK, ploughing at 54 cm
"	"	"	"	1965. Osijek	1966. maize	yes 18.85 q/ha of grain, ploughing at 54 cm	yes 18.61 q/ha, 534 kg/ha NPK, ploughing at 40 cm
"	Lessivé brown soil on carbonate loess, considerably anthropogenized	"	40, 50 and 60 cm and 300, 480 and 960 kg/ha NPK	1961. Kaštar	1964. sugar beet	yes 67.70 q/ha, ploughing at 60 cm	yes 55.10 q/ha of roots, 480 kg/ha NPK, ploughing at 60 cm

1	2	3	4	5	6	7	8
"	"	"	"	1961. Dušlar	1965. winter wheat	no	yes [illegible].18 q/ha, [illegible] kg/ha NPK, ploughing at 60 cm
Slavonia	Lessive brown soil on carbonate loess, intensively moistened	"	40, 50 and 60 cm and 300, 490 and 680 kg/ha NPK	1961. Rokovci	1966. winter wheat	yes 7.20 q/ha, ploughing at 40 cm	yes [illegible].90 q/ha, 680 kg/ha NPK, ploughing at 40 cm
"	Secondary pseudogley on carbonate loess	"	40, 100 cm extremely deep ploughing, 100x100 cm subsoiling; 560, 600, 1080 kg/ha NPK	1967. Lacići	1968. maize for grain	yes 30.56 q/ha of grain, very deep ploughing at 100 cm	yes 20.[illegible] q/ha of grain, 1080 kg/ha NPK, ploughing at 100 cm
"	"	"	40, 100 cm extremely deep ploughing, 100x100 cm subsoiling	1967. Lacići	1969. maize	no	yes 10.52 q/ha, 1080 kg/ha NPK, ploughing at 100 cm
"	"	"	"	1967. Lacići	1970. maize	yes 14 q/ha of grain, subsoiling 100x 100 cm	yes 29.6[illegible] q/ha of grain, 1080 kg/ha NPK, ploughing at 100 cm
"	Gleypseudogley	"	40, 55, 70 cm; 242, 582, 690 and 859 kg/ha	1968. Cačinci	1970. maize	no	yes 22.86 q/ha, 690 kg/ha NPK, ploughing at 70 cm
"	Pseudogley	"	35, 45 and 55 cm 360 and 520 kg/ha NPK	1968. Zdenci	1970. maize	no	yes 9.84 q/ha, 520 kg/ha NPK, ploughing at 4[illegible]

1	2	3	4	5	6	7	8
Bara-nja	Brown soil on carbo-nate loess	"	2o cm, 2o+2o cm, 3o cm, 3o+1o cm, 4o and 5o cm; 31o, 41o and 53o kg/ha NPK	1969. Bresto-vac	1971. winter wheat	yes 3.8o q/ha of grain, ploughing at 5o cm	yes 14.8o q/ha, 53o kg/ha NPK, ploughing at 3o + 1o cm
"	"	"	2o cm, 2o+2o cm, 3o cm, 3o+1o cm, 4o cm, 5o cm; 31o, 41o and 53o kg/ha NPK	1969. Bresto-vac	1972. sugar beet	yes 42 q/ha of roots, ploughing at 3o cm,+subsoiling at 1o cm	yes 36.17 q/ha of roots, 53o kg/ha NPK, plo-ughing at 5o cm
"	"	"	"	1972. Bresto-vac	1974. maize	no	no
Upper Sava Val-ley	Oligotrop-hic prima-ry pseudo-gley of loess-eleva-tion	humid	2o, 3o, 4o, 5o and 6o cm; 3oo, 49o and 560 kg/ha NPK	1962. Božja-kovina	1964. winter wheat	yes 7.62 q/ha of grain, deep ploughing at 6o cm	yes 3.33 q/ha of grain, 49o kg/ha NPK, deep ploughing at 6o cm
"	"	"	"	1963. Božja-kovina	1965. maize	no	yes 1o.24 q/ha of grain, 49o kg/ha NPK, deep ploughing at 6o cm
"	"	"	"	1961. Božja-kovina	1966. lucer-ne	yes 1o.oo q/ha of hay, deep ploughing at 6o cm	yes 16.4o q/ha of hay, 5oo kg/ha NPK, plo-ughing at 5o cm

CONCLUSIONS

The obtained investigation results point to the following conclusions:

– As deep tillage is primarily applied on heavier soils of unfavourable layering to serve ameliorative purposes, the greatest operation depths are applied here, as well as for crops with deep rooting (sugar beet and lucerne).

– Deep operations of basic tillage should be also applied in cases of compaction on the ploughing line and in subsoil due to inadequate application of agrotechnical measures, mechanization and traffic.

– The residual effect of deep tillage is accompanied by the residual effect of fertilizing, which is more marked than that of tillage. Besides, there is also interaction between tillage and fertilizing in relation to the yield.

– The residual effect of deep tillage as a rule decreases with time, but not always at the same rate; it can be "hidden" one year, to reappear the next year, depending primarily on the weather conditions.

– Deep tillage, as such, is a difficult and costly operation, but as an ameliorative measure it should be regarded as an investment, and in crops with deep roots as a necessity for obtaining good yields. It is well-known that, in our production conditions, deep tillage reduces the adverse effects of the climate, weediness and contributes to the yield stabilization.

– The residual effect of deep tillage should be made use of within certain limits, evaluating in each particular case the justification of reducing the depth, and even temporarily omitting the basic tillage, but without risking a drop in productivity.

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MINIMAL TILLAGE EFFECT ON SUGAR BEET YIELD

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ABSTRACTS

Minimal tillage variants have been investigated: plowing in upon the depth of 30 and 20 cm, rotorfresis application upon 8 and 4 cm of depth with pre-crops: winter wheat, corn and alfalfa on the alluvial deposition of black marsh soil as well as their effect upon the sugar beet yield /Yugoslav selection Al-Poly 1/. From the three-year experiments one can conclude that the plowing depth of sugar beet after the pre-crop of winter wheat and corn can be diminished to 20 cm; rotorfresis application on 4 and 8 cm effects a very significant statistical yield diminishment in relation to control variant.

MINIMAL TILLAGE EFFECT UPON THE SUGAR BEET YIELD

Introduction

Sugar beet is a very intensive row crop, for from all agricultural crops it has a heaviest demand towards tillage, i.e. in respect to the depth, time quality and mode of tillage. A classic system for sugar beet is as follows:

1.) Stubble plowing-in up to the 15 cm of depth, 2.) plowing upon the the depth of 25-35 cm, 3.) deep plowing upon 35-50 cm of depth in dependence on the plowing layer.

Many estates in productive conditions apply three plowings up to the depth of 40-50 cm / IPK Osijek - industrial Agricultural Combine - Osijek, Kurbarović, 1964 /.

We have undertaken as our task to investigate how the variants on minimal tillage on 20 cm, 8 cm and 4 cm of depth effect the sugar beet yield in comparison with the classical and usual depth of 30 cm after the pre-crop: winter wheat, corn and alfalfa.

Experiment methodics

In the period 1970/71 - 1972/73 the investigations were made by the method of field experiment of a stationary character.

The following variants were investigated: A. conventional - usual one and the control variant. B. The plowing upon

20 cm of depth. C. Rotary hoe application on 8 cm of depth. D. Rotary hoe application on 4 cm of depth.

The investigation was done after the following pre-crops: winter wheat, corn and alfalfa. The field experiments was established according to a randomized block system in six repetions. The size of the fundamental plot was fifty square meters.

The tillage was done in the following way:

A. Conventional tillage consisted of the following operation:

1. after the winter wheat, the stubble plowing-in on the 10-12 cm in depth and plowing on 30 cm. At the beginning of autumn disking was done in order to distroy weeds.

2. after the corn, plowing on 30 cm of depth with the use of heavy disk harrow.

3. after the alfaifa, the alfalfa plowing-in on 30 cm of depth with the use of heavy disk harrow.

Pre planting tillage was done in spring with pulvi mulcher, after all precrops.

B. Minimal tillage varinat on 20 cm of depth had the same operations as well as the variant A, the only difference being in plowing depth.

C. Rotary hoeing on 8 cm of depth, in dependence on the pre-crop consisted of the following operations:

1. After the winter wheat - the stubble plowing-in on 10-12 cm with the use of disk harrow during the autumn. In spring rotorfrasis was used / Rotorfraese LR 80-225 / on 8 cm of depth.

2. After the corn and alfolfa crop, only rotorfrasis was used on 8 cm of depth.

D. Rotary hoe on 4 cm of depth consisted of working operations as in variant C, while rotorfrasis / Rotorfraese LR 80-225 / was applied upon 4 cm of depth.

The experiments were located on alluvial black marsh soil in Pančevo marsh / according to classification Pavićević-Gligorić 1973 /.

Water-air propertius of these soils / according to Pavićević-Gligorić 1973 / were as follows:

Depth in cm	Soil texture	Volume gravity	Specific gravity	Porosity in % vol	Field capacity	Air capacity %
0- 20	clay-loam	1,30	2,73	52,4	44,0	8,4
30- 50	"	1,34	2,77	51,7	43,0	8,7
70- 90	clay	1,39	2,71	48,7	44,0	4,7
100-120	"	1,43	2,75	48,0	42,0	6,0

According to the usual laboratory analyses, the microelements contents was as follows: nitrogen 0,178 mg/100 gr of soil, P_2O_5 3,8 and K_2O 18,8. The value of pH in H_2O amounted to 7,8 and pH in KCL 6,6.

The fertilization system was as follows: in 1969 autumn 280 kg/ha of P_2O_5 was used in deep plowing as well as 200 kg /ha of K_2O. The nitrogen was used each year, after pre-crop of winter wheat and corn - 60 kg/ha before sowing and 60 kg/ha of pure nitrogen as a top fertilizer.

The sowing and the harvest were done by hand at an optimal time. Space between the rows was 50 cm, while in the rows 25 cm / 80.000 of plants/. For the experiment the Yugoslav variety of sugar beet was used: Al-Poly 1.

The crop conservation was efficiently done with the appropriate chemical means. The number of dustings depended on weed appearance. Herbicides were not used.

The sugar beet yields results were statistically worked out according to the variance analysis method.

Meterological conditions

The meterological conditions - the average monthly temperatures and precipitation amounts were given.

Average monthly temperatures / C^o / Precipitations in mm.

	1971	1972	1973	1971	1972	1973
I-XII	11,34	12,15	12,10	520	645,5	417,8
IV-IX	18,56	18,93	19,46	349,1	441,8	282,0

Tab. 1 Minimal Tillage and Pre-Crops Effect upon Sugar Beet Yield (mc/ha)

Tillage methods	1971 Preceding crops			1972 Preceding crops			1973 Preceding crops			Average Preceding crops		
	w.wheat	corn	alfalfa	w.wheat	corn	alfalfa	w.wheat	corn	alfalfa	w.wheat	corn	alfalfa
A	689,2	540,1	640,3	684,2	592,1	731	565,9	503,4	608,5	100	100	100
B	665,3	526,9	600,8	635,4	620,9	673,5	561,9	457,5	530,5	97,0	98,1	91,1
C	599,3	449,7	545,2	622,8	538,9	551,5	485,8	390,0	347,7	89,0	84,2	72,9
D	558,9	411,02	485,9	608,2	505,3	559,6	410,0	289,4	313,8	82,1	73,7	68,6
LSD 5%	26,09	27,5	34,48	40,69	31,8	46,3	40,6	43,2	32,0			
1%	36,21	38,1	47,84	56,46	44,1	64,3	56,3	59,9	44,4			

Taking into consideration the temperature conditions and precipitation distribution, one can consider that for sugar beet production meterological conditions were best in 1972.

Discussion results

The experiments with the study of the effects of minimal tillage variant as well as the pre-crop upon the sugar beet yield were given at the table 1.

From the results one can see that in all years the largest yield was obtained with the variants of the plow being used on the depth of 30 cm. The plowing on 30 cm of depth compared to that one on the depth of 20 cm caused a statistically significant growth of the alfalfa pre-crop yield in the first and the second experimental years / 39,5 mc/ha and 58,4 mc/ha /, and a very significant growth in the third year / 77,9 mc/ha /.

In the pre-crop of winter wheat, the deeper tillage had a slight advantage in 1971 and 1973 years / 3,58 - 4,0 mc/ha /, while in 1972 a larger yield was obtained in the variant of deeper plowing for 46,7 mc/ha, which is statistically significant.

On the pre-crop of corn, a deeper plowing had effected a statistically more significant growth of yield /1973/, while in other years these growths were not statistically significant.

Rotary how application on 8 cm in relation to the rotary hoe application on 4 cm of depth resulted in statistically very significant yield growth in 1971 after all pre-crops while in 1973 after the pre-crop of winter wheat and corn.

From all these experiment results one can conclude that plowing depth for sugar beet after pre-crops of winter wheat and corn can ve 20 cm.

According to the data om tillage expenses, by diminishing plowing depth from 40 cm to 30 cm and 20 cm, the expenses are being diminshed from 100% to 73.14 and 55.81% / Milojić-Otašević 1973/.

The problems of minimal tillage variants for sugar beet are very complex and require a study from the economic and theoretical views as well.

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LONG TERM EFFECTS OF TRACTOR TRAFFIC IN TWO FIELD EXPERIMENTS IN NORWAY

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ABSTRACT

Two field experiments, one on a loam soil, the other on a clay loam soil, were started in 1962 and were still running in 1975. The main results were: Reduced barley yields, increased infestation of couch grass and other weeds, reduced porosity and increased shear strength of the soil after cultivation and traffic at high soil moisture contents (soil matric suction <50 mbar). Tractor traffic before ploughing in the autumn showed much smaller effect on yields than traffic in the spring. Increased nitrogen application relieved the negative effect of autumn compaction but not of spring compaction. The negative effect of spring compaction was significant during the first two years after stopping the treatment.

INTRODUCTION

Soil compaction experiments were started up at the Department of soil fertility and management, Aas-NLH, Norway, in 1957. There were yield increases by rolling cereal fields with a Cambridge roller, and negative effects of traffic at a high moisture content (Njøs, 1962).

In 1962 two long term field experiments were started up to investigate possible build-up effects of long term soil compaction. It was felt that factorial experiments including different nitrogen level would be of special interest, as there might be a chance of possible interactions of nitrogen and compaction.

Many of the results of these two experiments cannot be presented in a short report, and a fuller account will be published later.

MATERIALS AND METHODS

The two long term compaction experiments described in this report are situated at the research farm of the Department of soil fertility and management. The coordinates of the farm are 59°40'N and 10°47'E. The elevation is 70 m above sea level.

The geology of the area is characterized by pre-cambrian gneissic rocks with a cover of post glacial marine deposits. In this region the highest level of sea water during the last glaciation was more than 200 m above the present sea level.

The two field experiments were placed on the lower slope of a long hill close to a terminal moraine. The slope of the site was less than 3 per cent. Soil characteristics are given in table 1.

Table 1. Soil properties of the experimental sites.

Experiment	Clay (Per cent)	Silt (Per cent)	Sand (Per cent)	Org.matter (Per cent)	pH(H_2O)
I 0-20 cm	26	42	32	6	5.7
20-40 "	26	42	32	2.7	5.8
40-50 "	26	52	22	0.2	6.3
70-80 "	35	52	13	-	7.0
II 0-20	29	39	32	5.8	5.7
20-40	-	-	-	2.5	5.8

The soil of Experiment I had a loam top soil over clay loam over clay. The soil of Experiment II had a clay loam top. The soils have been cultivated for a long time. They are poorly drained in natural condition with Munsell coulours of 5Y 4/2 dominant in the subsoil. The B-horizon is weakly developed due to the short time since the glaciation. According to the USDA Soil Taxonomy (1975) the soils might be classified as haplaquepts.

Climatic data are given in table 2. They are derived from Heldal (1975).

Table 2. Selected climatic data from Ås, Norway, 1931-60.

Month	Temperature mean, °C	Precipitation mm	Pot.evaporation mm	Radiation cal cm^{-2} day^{-1}
April	4.3	48		344
May	10.2	49	76	466
June	14.4	70	112	528
July	16.5	79	104	486
August	15.6	96	68	377
Sept.	10.9	86	35	238

The climate of the frost free season is characterized by a cold early spring, a presummer drought 1 May - 15 July and a very wet autumn from the 10 September. Normally the soil profile is recharged with water around the 10 September. The field capacity in these soils corresponds rather closely with a metric suction of 0.1 bar. The frost in most years does not go deeper than 0.5 m.

The treatments are given below:

Experiment I. A. Soil moisture, B. Compaction, i.e. tractor traffic, C. Loosening after compaction 1962-66, Nitrogen 1967-75.

The levels used for each factor were:

A0 Wet soil. Matric suction at 5 cm depth <50 mbar, at 20 cm depth 0-50 mbar.

A1 Moist soil. Matric suction at 5 cm depth 70-500 mbar, at 20 cm depth 50-300 mbar, or normal moisture level at soil cultivation. In most years the soil surface in the A1-condition had a grey to white appearance.

B0 No compaction in addition to normal tillage and harvest operations.

B1 One pass, wheel track by wheel track, with an 1800 kp tractor. Front wheel inflation pressure 2.5 kpcm^{-2} (250 kPa) rear wheel inflation pressure 0.9 kpcm^{-2} (90 kPa).

C0 (1962-66) No additional loosening of soil.

C1 (1962-66) One harrowing to loosen the soil before planting.
C0 (1967-75) 50 kg N per hectare in cereals, 75 + 37,5 kg N in grass.
C1 (1967-75) 100 kg N per hectare in cereals, 150 + 75 kg N in grass.

Experiment II. D-Compaction, E-Nitrogen

The levels used for each factor were:

D0 No compaction in addition to normal tillage and harvest operations.
D1 One pass, wheel track by wheel track, with an 1800 kp tractor, in spring before cultivation, generally in wet soil condition. Last year of compaction 1970.
D2 As D1 but before ploughing in the autumn, generally in a wet soil condition.
E1 47 kg N/ hectare in cereals, 72 kg N in grass.
E2 94 kg N/ hectare in cereals, 144 kg N in grass.
E2 140 kg N/ hectare in cereals, 216 kg N in grass.

The experimental design was a split plot factorial in both experiments. In experiment I, the A-treatments (wetness of soil) were on large plots, with the BC-treatments constituting the subplots. In experiment II, the D-treatments (compaction) were on large plots, with the E-treatments (Nitrogen) constituting the subplots. The results were treated with ordinary variance analyses.

RESULTS AND DISCUSSION

<u>Experiment I</u> Soil moisture (A) x Compaction (B) x Loosening (C), or N (C).

The results of the soil compaction experiment I are divided into two series,

the period 1962-1966 in which the C-factor signified a loosening of the top layer before planting

the period 1967-1975 in which the C-factor signified nitrogen.

During the period 1962-1966 there were 4 years of barley (<u>Hordeum vulgare</u> L.) and one year of rape (<u>Brassica napus</u> L.). During the second period there were 3 years of barley, 2 years of oats (<u>Avena sativa</u> L.) and 3 years of ley. For comparison barley and oats are grouped together as cereals.

In table 3 the yields of cereals (grain, 85 per cent dry matter) and hay (85 per cent dry matter) are given.

Table 3. Yields of cereals and hay in experiment I during the period 1962-75.

Treatment	Yields, ton per hectare				
	Cereals 1962-66	Cereals 1967-68	Hay 1969-70	Cereals 1972-74	Hay 1975
A0B0	2.6	2.3	8.0	4.3	9.9
A0B1	2.3	1.8	7.9	3.9	9.6
A1B0	3.7	3.1	8.2	4.5	9.4
A1B1	3.7	3.2	7.9	4.4	9.3
C0	2.9	2.4	7.3	4.0	9.2
C1	3.2	2.9	8.7	4.9	9.7
Significant effects	A,B	A,B,AB	C	A,B,C	[illegible]

During the period 1962-66 cultivation and compaction in a wet soil condition reduced the yields significantly in barley. The general lowering of the grain yield by compaction was 150 kg per hectare or 6 per cent. In a wet soil condition the yield reduction by compaction was 300 kg per hectare or 12 per cent, while in the drier soil condition the reduction was 60 kg per hectare, or 2 per cent.

During the years 1967-75 cultivation and compaction in the wet condition reduced cereal yields significantly as compared to soil handling in the dry condition. There was no build-up of this effect with time, as is clearly demonstrated by the numbers in the table. On the contrary, in 1975 (first year's ley) the yield of hay was highest for A0. The reversing of the soil moisture effect of the previous years might be a kind of hysteresis effect. During the years with low yields there may have been a build-up of nutrients in the aggregates of the A0 plots.

The effects of compaction did not increase with time. At a high soil moisture content the effect of compaction on the grain yield in 1967-68 was -540 kg per hectare, or -23 per cent, while it was -400 kg per hectare, or -9 per cent in the 1972-74 period. In both cases the compaction effect in a dry soil was negligible (-90 to -60 kg per hectare). There was no significant interaction between nitrogen and compaction.

Early planting is one of the reasons for the high yields in 1972-74, the average planting time being 27th April, while it was 17th May in 1967-68. Elsewhere it has been demonstrated that a slightly higher soil moisture content at cultivation than the crumbling stage did not decrease yields when planted very early (Njøs, 1976).

The straw yields mainly followed the grain yields. On the average, however, the grain percentage was lower for the A0B1-treatment than for any other treatment. Higher nitrogen (C) level increased the yield of straw more for the wet soil condition than for the dry.

The <u>lodging</u> percentage in cereals was decreased by compaction of wet soil, but not by compaction of dry soil.

The <u>weed</u> population was generally increased by wet handling of the soil. Cultivation at high soil moisture increased the stand of sow thistle (<u>Sonchus arvensis</u> L.).

For couch grass (<u>Elytrigia repens</u> (L), Nevski - formerly <u>Agropyron repens</u> L.) three years of observation of the percentage cover gave the following results:

A0B0	A0B1	A1B0	A1B1
12	22	5	5

The couch grass showed its highest competition ability after wet compaction.

<u>Aggregate size distribution</u> (Njøs, 1967) in the cultivated layer was a rather sensitive measure of the effect of compaction and moisture content during soil treatment. There were large differences between years. The two extreme years were 1962 and 1974, with a very coarse soil structure in 1962 and a fine structure in 1974 (72 and 22 per cent of aggregates larger than 6 mm, respectively). In table 4 the effects of treatments A and B on three aggregate size classes are given for the periods 1962-66, and 1967-74.

Table 4. Aggregate size distribution in 0-5 cm depth in experiment I.

Treatment	Per cent in size class >6 mm 1962-66	>6 mm 1967-74	6—0,6 mm 1962-66	6—0,6 mm 1967-74	<0,6 mm 1962-66	<0,6 mm 1967-74
A0B0	61	40	31	45	7	12
A0B1	69	54	24	34	6	10
A1B0	49	29	38	51	12	13
A1B1	44	30	40	49	15	19
Sign. effects	A,AB	A,B,AB	A,AB	A,B,AB	A	A,AB

During the first year of ley, 1969, there was a noticeable increase in coarseness of soil structure. As seen from the table there is a general increase in fineness of aggregates from the first to the second period even for the wet soil treatments. On the other hand the effect of tractor traffic at high soil moisture content is more marked in the second than in the first period.

The porosity of the soil that had been handled in the wet condition decreased during the initial phase of the experiment but seemed to be stable during the remaining period. See table 5.

Table 5. Porosity of the soil in experiment I.

Treatment	Porosity, volume per cent				
	10-15 cm			25-30 cm	
	1963-65	1969-71	1972-74	1969-71	1972-74
A0B0	51	48	46	46	42
A0B1	49	46	46	43	44
A1B0	53	51	53	46	46
A1B1	50	50	51	45	46

The numbers for 25-30 cm are not reliable due to inherent soil variation in this depth. It is still a tendency of a lower porosity for wet compaction than for dry compaction even in the 25-30 cm depth.

Shear strength was measured by a vane borer (Schaffer, 1960) Results of measurements in 1966 and 1975 are given in table 6.

Table 6. Shear strength of the soil in experiment

Treatment	Shear strength, kp/cm^2					
	1966			1975		
	0-10 cm	10-20 cm	20-30 cm	0-10 cm	10-20 cm	20-30 cm
A0B0	0.9	0.9	1.0	0.6	0.5	1.0
A0B1	1.1	1.1	1.2	0.6	0.7	1.2
A1B0	0.6	0.8	0.9	0.3	0.4	0.7
A1B1	0.9	1.0	1.1	0.4	0.5	0.9

The results indicate a higher shear strength after wet than dry soil treatment and an increased shear strength after tractor traffic.

The nitrate content of the soil aggregates were investigated in soil samples from 1974. After dry sieving, the aggregate fraction 6-2 mm was extracted by 2 mol/dm^3 KCl and analysed according to Henriksen and Selmer-Olsen (1970). The results are given below:

Pre-treatment	NO_3-N, kg/ha, 0-5 cm depth			
	A0B0	A0B1	A1B0	A1B1
Aggregates 6-2 mm	6.5	7.6	9.5	5.5
" , crushed	7.0	8.3	5.5	5.8

The higher nitrate content of the soil that had been handled wet is probably explained by the previous year's lower yield as well as a "capsule" effect. Nutrients stored in dense aggregates may be released in a ley due to a dense root system and long growth season (see

Experiment II. Compaction (D) x Nitrogen (N)

This experiment was started up in the autumn of 1962, and harvested for the first time in 1963. The last compaction was carried out in the spring of 1970. Only the nitrogen plots were treated during the years 1971-73. In 1974 the yield (1st year ley) was not harvested, but in 1975 one cut of the 2nd year ley was harvested. This year the whole field received the same amount of nitrogen. The results are suited for a subdivision in the period 1963-70 and the period 1971-75.

In table 7 the yields during the compaction period (1963-70) and residual effect period (1971-75) are presented.

Table 7. Yields of cereals (grain), rape (seeds) and hay in experiment II.

Treatment	Yield, tons per hectare 1963 - 70			1971 - 75		
	Cereals 4 years	Rape 2 years	Hay 2 years	Cereals 1971-72	Cereals 1973	Hay 1975
D0	3.6	1.3	11.1	3.1	3.5	7.7
D1-spring	2.9	1.2	10.3	2.9	3.6	7.7
D2-autumn	3.5	1.2	11.1	3.1	3.4	7.6
N1	2.9	1.1	9.6	2.1	3.0	7.5
N2	3.4	1.3	11.1	3.1	3.6	7.6
N3	3.7	1.4	11.7	3.0	3.8	7.9
Significant effects	D,N,DN	D	D,N	D	N	N

The table shows the significant decrease in yields by spring compaction during the first period. The decrease in yield by this treatment was 20-11-7 percent for cereals, rape, and hay, respectively. For the autumn compaction (before ploughing) the yield decrease relative to D0 was 4-8-0 per cent for cereals, rape and hay, respectively.

Increased N-application decreased the negative effect of autumn compaction but not of spring compaction. At the two higher levels of N the effect of spring compaction was higher than at the lowest N-level.

In the second period there was a significant residual effect only during the first two years after compaction. The first year's crop was oats, the second barley. The effect on grain yields in the spring compaction treatment (treated the previous period) was -150 kg per hectare in oats and -220 kg per hectare in barley. There was no significant residual effect of the autumn compaction.

In 1973 there was no significant residual effect of compaction, and this was the case in 1975 as well. Thus, in this experiment on a clay loam soil, the negative effect of compaction during the period 1962-1970 lasted two years after the treatment was stopped, and did occur for the spring compaction only.

The straw yield was affected somewhat differently from the grain yield. It was least for the autumn compaction. The grain percentage was significantly lower for the spring compaction than for untreated.

Lodging in the cereal years increased with increasing N-applications. It was slightly higher for spring compaction than for autumn compaction.

The weed population was increased by the spring compaction. In fact there was a residual effect even as late as in ley 1975.

The numbers below give weed cover percentage in experiment II as an average over years (10) with available observations:

Treatment	Per cent weed cover
D0	9
D1	22
D2	9

The population of coach grass (Elytrigia repens (L). Nevski) increased after spring compaction.

In the ley years 1967-69 the percentage of clover was observed. The results showed that there was a higher clover percentage in the second cut after spring and autumn compaction, as compared to untreated (59-58-48, respectively).

The porosity of the soil was slightly influenced by soil compaction, in the upper subsoil. This effect was observed as late as 1975, 5 years after the last compaction, as shown by the numbers below (20-25 cm depth).

Treatment	Porosity, volume per cent Air (pF2) 1970	1975	Total 1970	1975
D0	6	11	47	50
D1	4	7	43	48
D2	5	9	45	49

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GEOMETRICAL STUDY OF THE DIFFERENT MOLDBOARD PLOUGHS RELATED TO THE SPANISH SOIL CONDITIONS.

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ABSTRACT

A number of 22 different moldboard ploughs were studied from the geometrical point of view, as a first step in order to adapt these tools to the different Spanish soil conditions. For this purpose, an apparatus was constructed to measure the coordinates of the moldboard surface, having established around 500 points for each moldboard. The surfaces adjusted were of the polinomial type, explicit in z (cubics and quadrics) which yielded a very high multiple correlation coefficient. For further research it has been outlined the hyperbolic paraboloid of the type $z = axy + by^2 + cy$ as the most suitable. With the aid of a minicomputer, the moldboard shapes were plotted in different positions.

Introduction

The effects of the different tillage practices in the ground to the growing plants until they are harvested are difficult to evaluate, because of so many factors that are involved. In some cases some subjetiv criteria have been established which have affected the results negatively. The tillage techniques have to be reconsidered to be adapted to the new circumstances.

In Spain 90% of the tractor ploughs are moldboard ploughs. Most of these ploughs are designed empirically, modifying the surface by the method of "try and error". The design of the moldboard ploughs has been made more as an art than as a technic.

Objetives of the research and precedents

The lack of energy in agriculture has obliged to search for a better use of the available energy. This is one of the reasons why we have begun a research program to adapt the moldboard ploughs to the different Spanish soil conditions.

As a first step we have studied -from the geometrical point of view- the surfaces of the moldboard ploughs available in our country.

Many authors have studied the geometry of the moldboard ploughs, but considering the curves that integrate those surfaces: their curvature and the angles that they make with different planes, as for example Söhne (1959) and Florescu et al. (1968).

Gorjatschkin (1909) established the three main angles of a wedge to define the moldboard surface and to explain the work done by it: the vertical angle of cutting and elevation, the horizontal angle of side thrust and the vertical one of turning and inverting the soil layers.

Nichols and Kummer (1932) divided the surface of the moldboard plough into three sections: the lower, or share portion, for breaking the soil; the central area for pulverizing it and the upper part for turning and inverting it.

Königer (1949) classified the moldboard shapes as ruled surfaces of different kinds.

But in general or at least in Spain sistematic studies have not been made to establish the ecuations that define the active surface of the moldboard ploughs. Having these ecuations, it is possible to correlate them with the results obtained ploughing the different types of soils in order to obtain the most suitable moldboard shape for each condition.

Methods and results

In order to make the measurements of the coordinates of the moldboard surface it was constructed an apparatus called "coordinatometer", formed by two parallel gridded planes. The tool which shape is to be described can be oriented so that the straight line between the moldboard and the share be horizontal and lean in one of these planes, and corresponds to the x axis. The holes are in each direction 25 mm apart. The needles go through the corresponding holes until their points touch the surface (fig. 1). The contour is determined with more density of measurements (one point each 5 mm).

Stone and Gulvin (1969) indicate that there are necessary 250 points in order to verify the quality of manufacture of a moldboard shape. We have established as a mean, 500 points for each moldboard.

We have adjusted different kinds of polinomial surfaces explicit in z (cubics and quadrics) adjusting the regression coefficients with a computer CYBER-72 CONTROL DATA of 75 Ks. The surfaces obtained of the quadric type, yielded a very high multiple correlation coefficient (R varied from 0,96 to 0,99) and were in general of the type of hyperbolic paraboloid and a few also of elliptical paraboloid. (Table 1). We have adopted as the most suitable form to define the moldboard shape the hyperbolic paraboloid of the type:

$$z = axy + by^2 + cy$$

in order to go ahead with the research outlined.

We have stated that there are some slight differences between two, in theory, identical moldboard shapes because of the manufacturing methods (warping distortions, bending and hardening operations, etc). But as a whole the method can be considered of a high accuracy.

Graphic representation

Through the use of a mini-computer (HP-9830) equipped with a plotter, we have represented the 22 moldboard ploughs considered in the manufacturing coordinates representation (fig. 2), in the working coordinates representation (fig. 3) and in perspective (fig. 4). Because of the lack of space we give here only a moldboard shape as an example. To change from the manufacturing, to the soil or working coordinates we have had to rotate the surface an angle φ around the y axis and an angle θ around the x axis so that the edge forms the vertical wall of the furrow.

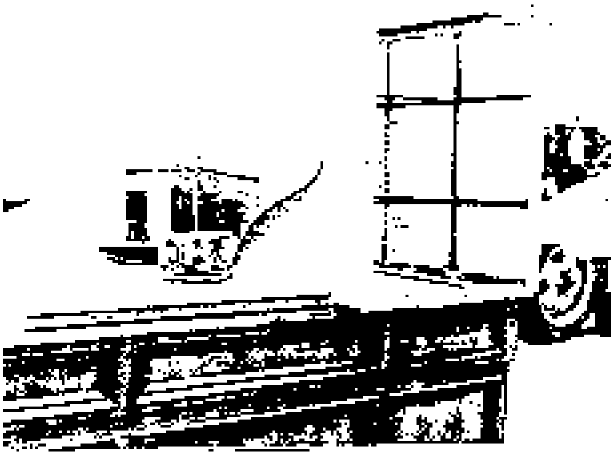

Fig. 1 - Apparatus to measure the coordinates of the moldboard shapes (coordinatometer)

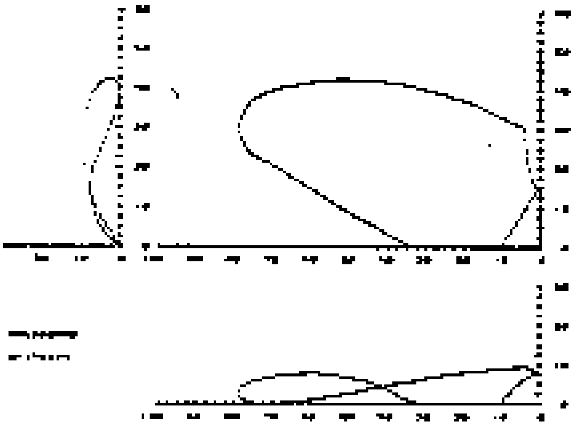

Fig. 2 - Representation of the manufacturing coordinates of a moldboard shape.

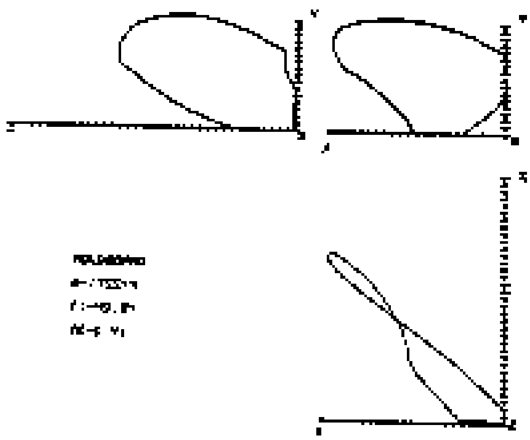

Fig. 3 - Representation of the same moldboard shape in the soil-coordinates.

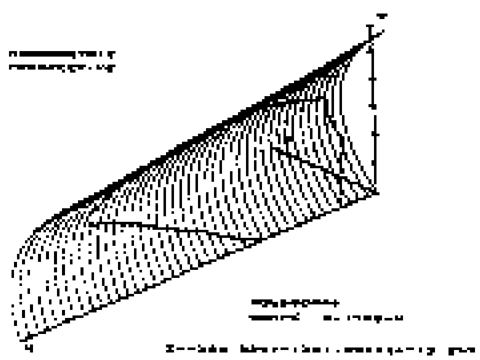

Fig. 4 - Perspective of the same moldboard shape.

TABLE I - Equations obtained for some moldboard surfaces

Moldboard	Equations (*)	R	Surface
B-1776C	$z=32{,}61x^2-469{,}94xy-1656{.}51y^2+43x+718{,}83y+7$	0,97	Hyperbolic paraboloid
	$z=-137{,}31xy-2076{,}74y^2+753{,}06y$	0,96	"
B-1755-4	$z=-26{,}02x^2-482{,}58xy-1231{,}48y^2+71{,}08x+756{,}36y-10{,}9$	0,99	"
	$z=-301{,}24xy-1401{,}54y^2+776{,}93y$	0,99	"
B-1781-3	$z=-8{,}90x^2-622{.}72xy-1684{,}55y^2+39x+992y-5{,}2$	0,99	"
	$z=-493{,}23xy-1863{,}47y^2+1021{.}61y$	0,99	"
B-1753-4	$z=-43{,}77x^2-309{,}83xy-1287{,}66y^2+38{,}57x+708{,}18y-2{,}6$	0,98	Elliptic paraboloid
	$z=-303{,}12xy-1348{.}49y^2+735{,}70y$	0,99	Hyperbolic paraboloid
B-1753-0	$z=-20{,}24x^2-694{,}83xy-1791{,}90y^2+63{,}94x+612{,}13y-7{,}3$	0,99	"
	$z=-439{.}35xy-2044{,}41y^2+833{,}96y$	0,97	"
B-1753-2	$z=-46{,}23x^2-652{,}82xy-1715{,}37y^2+75{,}12x+903{.}42y-9{.}7$	0,99	"
	$z=-466{,}38xy-1906{,}57y^2+927{,}01y$	0,99	"
Chirlaque-1	$z=248{,}83x^2-1042{,}94xy-595{,}89y^2-67{,}96x+652{.}33+3{,}5$	0,99	"
	$z=-485{,}51xy-1097{,}94y^2+647{.}82y$	0,97	"
Chirlaque-2	$z=206{,}3x^2-971{,}42xy-643{,}22y^2-65{,}43x+736{.}71y+4{,}5$	0,99	"
	$z=-503{.}83xy-1038{,}83y^2+719{.}39y$	0,98	"
David	$z=-72{,}94x^2-436{,}53xy-637{.}82y^2-4{.}09x+667{,}43y+4{,}3$	0,99	"
	$z=-715{,}63xy-378{,}08y^2+669{.}5y$	0,99	"
B-1781-2	$z=19{.}5x^2-482{.}13xy-1671{,}22y^2+17{,}89x+838{.}15y-3{,}6$	0,99	"
	$z=-330{,}4xy-1844{,}6y^2+852{,}11y$	0,99	"

(*) x and y in m, z in mm.

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ALTERNATIVES FOR PLOUGHING

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ABSTRACT

Experimental evidence from 8 years' research on alternative tillage systems shows that, at least in a wide rotation, ploughing is not always needed to obtain good growth. Alternatives may vary from non-ploughing (for cereals) to deep cultivating (for root crops). In any case a good seedbed must be prepared, rapid and uniform emergence being prerequisite to high yields.
Alternatives for ploughing may be incorporated into a system of rational tillage, aiming at maximum net profit from the farm for the duration of the (intensified) crop rotation.

Ploughing is the main part of the tillage system and, therefore, an integral part of the modern farm management which aims at maximizing net profit from the farm for the duration of the crop rotation (Van Ouwerkerk, 1974). This goal may be achieved by intensification of the crop rotation - to maximize gross yield per ha - and by rationalization of tillage practices - to minimize total production costs, of which roughly 15% may be charged to soil tillage.
The modern plough is reliable but slow: maximum forward speed is about 7 km/h (Boekel and Van Ouwerkerk, 1967). Modern, powerful tractors >100 HP make the use of very wide, multi-body ploughs possible. However, apart from the fact that these ploughs are not easy to handle, they pay only on very large farms, which are uncommon in The Netherlands. Therefore, alternatives for the plough are currently sought actively.
In selecting an alternative, one must be clear about the objectives. The primary objective of ploughing is loosening the soil and restoring its homogeneity. Secondary objectives are incorporation of crop residues, mixing of organic and mineral fertilizers with the soil, control of weeds and of pests and diseases (Kuipers, 1963). Insight into the practical possibilities and the fundamental background can be gathered from the results of research on alternative tillage systems carried out during 1968-1975 (Bakermans et al., 197-; Van Ouwerkerk, 1976).

TILLAGE SYSTEMS

In general, any tillage, especially ploughing, has a loosening effect on soil structure while traffic has a compacting effect. According to the extent to which loosening effects are incorporated and compacting effects are tolerated, four different tillage systems can be distinguished (table 1).
In the *traditional* system the soil is loosened deeply and intensively each year by ploughing. However, in spring the soil is usually compacted to the extent that the loosening effect is completely nullified.
The experimental *loose-soil husbandry* tries to improve this situation

Table 1. Tillage systems.

Loosening effects	Compacting effects	Denomination
+	-	loose-soil husbandry
+	+	traditional tillage
-	-	rational tillage
-	+	zero-tillage

by maximizing the loosening effect and by minimizing compaction through rationalization of traffic, irrespective of costs.
In its full sense *zero-tillage* means that any tillage whatsoever (seedbed preparation included) is omitted (Bakermans and De Wit, 1970). However, for potatoes this is impractical as mechanical lifting is impossible without proper ridges. Therefore, by way of concession, a seedbed is made by full-width rotovating to a depth of 7 cm. In this system compaction of the soil predominates. As a consequence soil structure soon becomes homogeneous, dense and hard (Van Ouwerkerk and Boone, 1970; table 2).

Table 2. EHF "Westmaas" (1968-1971) - Pore space (%, v/v), averaged over 4 years and 5 crops.

Depth (cm)	Tillage system		
	traditional	zero	rational
2-7	49.5	45.9	48.9
12-17	46.7	44.3	49.6
22-27	46.3	41.7	49.9

Rational tillage is distinct from the other three systems in that it aims at increasing the efficiency of soil tillage in a technological and economical sense to maximize net profit, averaged over the duration of the crop rotation. Therefore, frequency, depth and intensity of soil loosening are made to correspond to the specific demands of the individual crops in the rotation with respect to soil structure and weeds. In practice this simply means that tillage in its broader sense (i.e. including traffic over the field) is restricted to a rational or a reasonable extent. This may be a reduction to nought (as for cereals), but also ploughing to 25 cm (as for sugar beet). It is self-evident that one tries to safeguard the loosening effect as much as possible by rationalization of traffic (combined cultivations, wide implements etc.).

EXPERIMENTS

Our first experiment (ZWZH 1310) was conducted during 1968-1971 in a fairly wide, five-year rotation, viz., alfalfa or ryegrass - sugar

beet - winter wheat + ryegrass - potatoes - barley or oats + ryegrass. In this experiment rational tillage was compared with traditional tillage and zero-tillage (table 2). The experiment was laid out on a light clay soil (27% clay; 3.0% o.m.).
In 1971 a new experiment (Wo 38) was started on a heavy loam soil (21% clay; 2.9% o.m.). Here rational tillage is being compared with loose-soil husbandry and zero-tillage in an also fairly wide, four-year rotation, viz., sugar beet - barley + ryegrass - potatoes - winter wheat + ryegrass. The essential features of the three systems are shown in table 3.

Table 3. EHP "Westmaas" - Tillage systems compared since 1971.

Crop	Tillage system		
	loose-soil (A)	zero (B)	rational (C)
winter wheat	plough 20 cm + sowing (1 pass); no seedbed prep.	cultivator 3 cm + sowing (1 pass); no seedbed prep.	cultivator 12-20 cm + sowing (1 pass); no seedbed prep.
sugar beet	plough 25 cm seedbed prep. + sowing (1 pass)	- direct drilling	plough 20 cm seedbed prep., sowing (2 passes)
spring barley	cultivator 3 cm plough 20 cm seedbed prep. + sowing (1 pass)	cultivator 3 cm - direct drilling	cultivator 3 cm cultivator 15-20 cm seedbed prep., sowing (2 passes)
potatoes	plough 25 cm N-fert. + seedbed prep. + planting + ridging (1 pass)	- rotovator 7 cm + planting (1 pass) row-rotovating + ridging (1 pass)	plough 20 cm seedbed prep., planting (2 passes) row-rotovating + ridging (1 pass)

With respect to soil structure results until now were similar (table 2, fig. 1) for both experiments, mainly due to the fact that wheelpath or bed systems (Kouwenhoven, 1975) could not yet be fitted into the loose-soil system.
Differences in total pore space between systems A (loose-soil husbandry) and C (rational tillage) were only slight at the 2-7 cm depth. At a depth of 12-17 cm A was equal to or slightly better than C (effect of seedbed preparation) while at a depth of 22-27 cm A nearly always had a larger pore space than C (effect of working depth). With zero-tillage (system B) soil structure was much worse: at 2-7 and 12-17 cm depth it approached the maximum density for this soil (pore space 39%, v/v). In the 22-27 cm layer, not prone to compacting effects, pore space was somewhat higher.

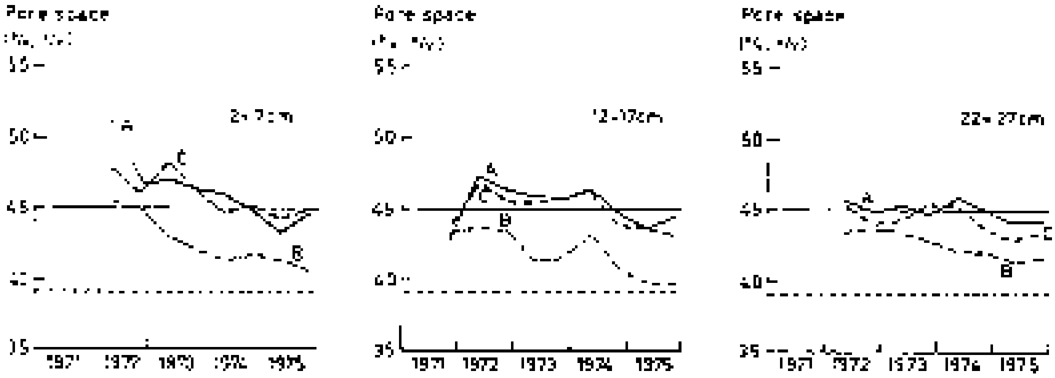

Fig.1. EHF "Westmaas" (1971-1975) - Pore space, averaged over 4 crops. A = loose-soil husbandry; B = zero-tillage; C = rational tillage.

It is striking that, in all systems, pore space decreased in the course of time and even in systems A and C fell below the critical level for this soil (pore space 45%, v/v; air content at pF 2.0 about 10%, v/v). However, this trend was due mainly to the effect of bad weather conditions during autumn and winter 1974/1975. Thanks to the subsequent fine, dry summer, distinct signs of recovery could already be noted in the autumn of 1975.
Averaged over the years there were no significant differences in yield level between systems A and C for the crops studied.
With zero-tillage, the yield level was clearly lower, especially with root crops. Experimental evidence suggests that actual differences between systems A and C were due mainly to differences in quality of the seedbed or in amount and aggregate diameter of the loose soil in the potato ridges. With respect to zero-tillage it can be stated that negative effects of poor soil structure predominated. These negative effects may be compensated, at least partly, by preparing a good seedbed and by increased nitrogen dressings.

To what extent these results will hold for extremely narrow rotations is being studied in new field trials. Preliminary results indicate that further intensification of the crop rotation and a higher net return are possible only if labour-saving alternatives for ploughing and other important parts of the tillage system are introduced.

ALTERNATIVES FOR PLOUGHING AND RATIONAL TILLAGE

Alternatives for ploughing depend on crop rotation, soil type, and climate. Moreover, in my opinion, the alternatives should contribute as much as possible to the net profit from the farm for the duration of the crop rotation.
The most promising alternative for ploughing found so far is the modern rigid-tined cultivator or chisel plough which produce about the same intensity of loosening as the moldboard plough. However, depending on the way of soil breaks up between the tines, the effective average working depth of a cultivator is up to 5 cm shallower than the depth of the tines. Therefore, below 20 cm depth one has to reckon with a denser soil than with ploughing. Hence, it is not advisable to continue cultivating to this depth for many years. As a cultivator does not invert the soil, green crops cannot been turned under properly. Therefore, they have to be killed chemically. When they have produced much bulk, a shallow pre-treatment with a full-width rotovator has to be added. As these are costly, time consuming measures, ploughing is

preferred in this case. For the same reason the spading machine is now obsolete in Holland. The non-inverting action of the cultivator has the big advantage that potatoes lost at harvest stay in the topsoil where they have the best chance of being frost-killed (Lumkes, 1974). However, not inverting the soil means also that sugar beet tops and leaves as well as rhizomatous weeds stay near the surface. Hence, for spring cereals and sugar beet, seedbed preparation, serving also as mechanical weed control, is indispensable. Also later, intensive weed control has to be continued.

Generally, there are no objections to replacing ploughing by cultivating. However, in some cases a part of the zero-tillage system may serve as an alternative. For instance, in the narrow crop rotation sugar beet - winter wheat + ryegrass - potatoes, deeply loosening of the soil may not be necessary for winter wheat. When excessive rutting has not occurred the wheat can be drilled easily with a triple disc machine. Other possibilities are using a semivator or broadcasting the seed and working it under with a spring tined cultivator. After potatoes, however, it is imperative to level the surface and to mix the fine soil created at harvest with coarser material from beneath to re-establish contact with the subsoil and to create enough storage capacity for water. This is accomplished in one pass with the rigid-tined cultivator, provided 6 to 10 HP per tine is available. After winter wheat ploughing is preferred, as outlined before.

Along these lines alternatives for ploughing may be found and incorporated into a system of rational tillage. While not denying that high yields are rightly looked upon as the basis for a high net profit, it is a matter of weighing costs and returns to determine to what extent the specific demands of crops with respect to soil structure and weeds may be met.

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Multi-powered soil tillage implements

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ABSTRACT

General properties of multi-powered tools are discussed on the basis of rotation, oscillation and translation.
Specific work of a rotary tiller is determined (indoor) in clay and sand.
Field measurements with machine and soil data are given for Dutch machines like the rotary digger, the kuryvator and the tine-equipped machines for seedbedpreparation.

PRESENT INTEREST

Multi-powered soil tillage implements become more and more popular in the Netherlands, especially on silt and clay soils with workability problems (from appr. 30% <16µm).
Also on these soils, the farmer is forced, to grow rootcrops in a narrow rotation nowadays. The high value potato-crop for instance, demands a well crumbled plantbed, to favour a prosperous growth and a full mechanical harvest of the ridges.
Sugarbeets on their turn need a rather fine and flat seedbed, to provide a good germination, care and harvest. Heavy clay, used as arable land, is only well suited for cereals and rape, which crop has to be sown very quick after wheat-harvest in August. In both this circumstances multi-powered implements, can perform a good tilth within a short period and very often one operation will be sufficient.
Drawn implements move straight forward only. Thus, the tilth is very dependend on the initial soil condition and can be effected only by tractor speed.
The energy transmission by wheels will cause structure damage (compaction ect.).
Rotating and oscillating tools, as examples of multi-powered implements are preferred sometimes, in spite of their more complex mechanism.
Draft is reduced or replaced by rotating energy which is transmitted by p.t.o. very efficiënt.
This rotation, superposed on forward speed, offers many possibilities for soil manipulation.

PATH OF MOTION

In fig. 1 the different applied principles of rotation, oscillation and translation are presented.
Rotation and translation are powered with constant speed (producing cycloids resp. diamond pattern) while oscillation is generated in the same way as the well known cutter bar, producing sinus curves.
The tillage intensity generally is influenced by the bitelength l
$\left(\frac{\text{forward speed}}{\text{number of tools/sec}}\right)$ and the tool speed.
Tines are well suited for transport and pulverisation of bare, workable soil (situation in springtime), while blades and knifes can cut rather wet soils and plantresidues (practised mostly after harvest).

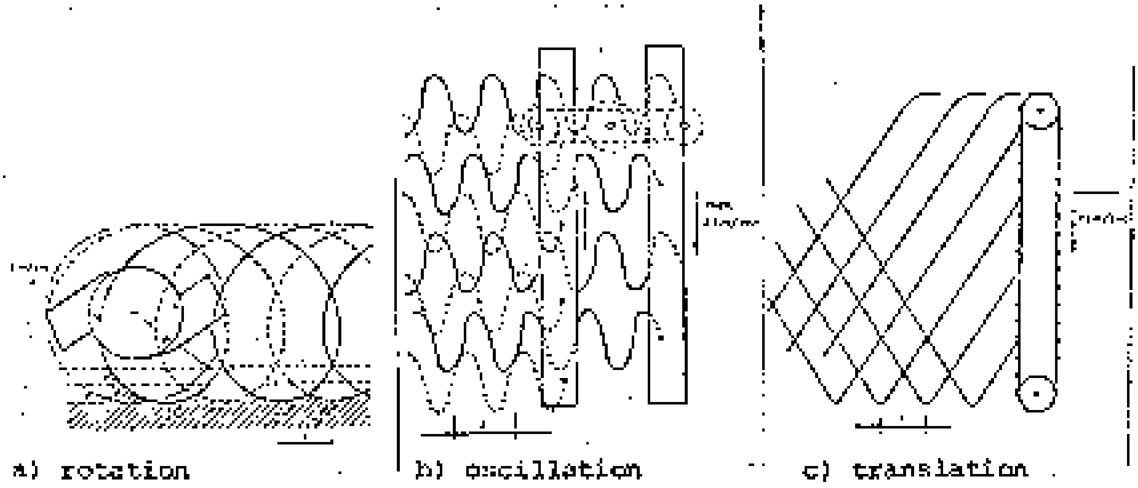

Fig. 1 Path of motion for different principles (forward speed 1 m/sec)

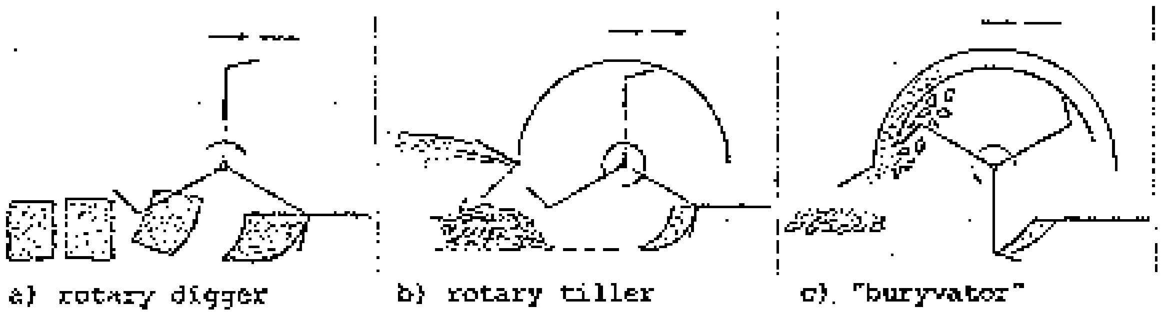

Fig. 2 Three principles of vertical rotation.

APPLICATION OF VERTICAL ROTATION

Vertical rotating tools act with an open furrow; thus the whole soil mass is transported.
Clods and plant residues will meet with tool forces from top and with counter pressure from bottom, between which this materials will be cut down ect.
The generated soil flow can be manipulated by auxiliary parts in behalf of crumbling, leveling, ridging, mixing, segregation ect.
In fig. 2, the principle of three machines is presented:
a) bites turned or pushed down into the furrow (rotary digger)
b) bites bumped against cover, flap or ridging body (rotary tiller)
c) bites trowed through the grid (buryvator)

SOILBIN MEASUREMENTS

The torque requirement of the rotary tiller with blades has been determined in clay and sand (Burema 1976).

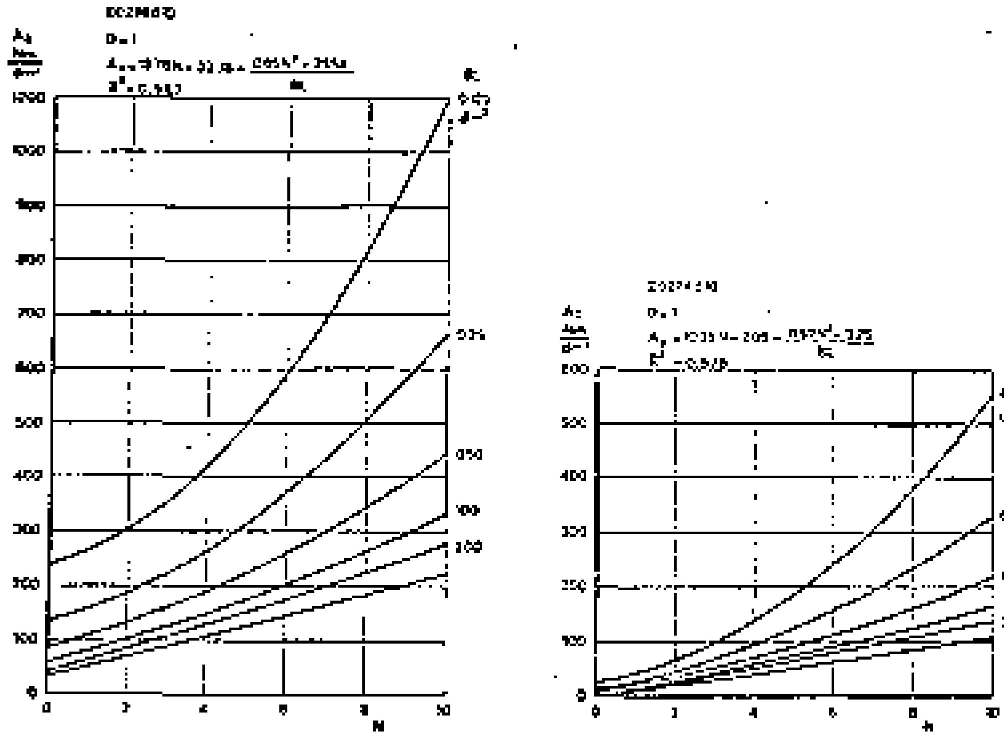

Fig. 3 Relation between specific work (As) and blade speed N (r.p. sec), for different bites (B)on clay (K) and sand (Z) at a depth of 1 dm.

According to the formulas (fig. 3), the specific work increases cubic with circumferential speed and decreases linear with bitelength and forward speed.
The rotary tiller enables to put in a lot of energy into the soil, used for cutting, acceleration ect.
In the field, the resistance of agricultural soils will lie in between this cohesive and frictional indoor-soil, and the same model will hold in principle.

FIELD MEASUREMENTS

1) Rotary digger (fig. 2a)
Measurements have been carried out with two types of rotary diggers, pushing, resp. tipping the bites from the blade.
The bitelength has to exceed the depth (appr. 25 cm) to get enough clearance.
At a gross capacity of 0.4 ha/hour, the energy consumption of both machines (width appr. 2 m) will amount to appr. 20 Hp on dry and wet silt soil. On clay soil 40-50 Hp is needed, especially on wet soil.
Due to sticky problems, a more difficult removal of the bites is found by pushing, compared with tipping.
Ploughing instead of digging needs almost half of the above mentioned energy, but the wheelpower is transmitted with relatively low efficiency.

2) Buryvator (fig. 2c)
The buryvator has to operate with a minimum bitelength, according to the interspace of the grid (5 cm), to enable the segregation of sods.
The power requirement of this machine (width 1.50 m, depth 15 cm) is rather high on the compacted turf especially on heavy silt and clay soils (appr. 70 Hp at 2 km/hour). On sand and peat soils, 45 Hp appears sufficient.

3) Machines for seedbedpreparation

In spring 1975 powered implements have been tested with the spring tine cultivator as control. General machine- and soildata (4 repetitions) are summarised in table 1.

Cultivator: total power is delivered by the drawbar and amounts to appr. 5000 N. Specific work and crumbling effect are low. Classification in this way (clods <20 mm) is easy to determine and to evaluate (compare with Steinkampf, 1974).

Oscillating harrow: without gearbox, the technical tinespeed can hardly be adjusted.
The bulldozing effect during shallow work is favoured by a blade, to level the soil in front of the machine. The draft is rather high (appr. 7000 N) and the manageable specific work remains low.
The requi-red torque remains the same, independent from forward speed. Thus, % p.t.o. power decreases with increasing forward speed.

Horizontal harrow: stationary, the tines describe circular touching prints. At low r.p.m the machine looks like the oscillating harrow more or less; at higher r.p.m the performance achieves those of the rotary tiller.

Rotary tiller: the vertical moving tines will mix dry top soil with relatively wet subsoil. By means of the big diameter, ridging is possible later on.
Very high specific work is manageable and gives agressive action. Caution in handling is desired.

Implement	Path of motion	Width per tine (cm)	Forward speed (m/sec)	Max. tine technical speed (m/sec)	P.t.o. power in % of (P+L)	Spec. Work kg [illegible]	Crumbling effect [illegible]	Capacity	Special tool effect	Soil type
Cultivator	straight	12.0	1.1-2.0	-	0	40-45	6.7-8.3	high	levelling	lighter or shallow
Oscillating harrow	linear	8.[illegible]	0.7-1.4	1.7-3.4	30-63	120-150	6.0-8.0			
Horizontal harrow	hor. cycloid	16.5	0.4-1.3	3.5-6.3	45-92	81-291	5.7-8.[illegible]			
rotary tiller	vert. cycloid	15.6	0.6-1.2	10.6-14.0	89-95	95-316	7.8-8.2	low	crumbling	heavier or deeper

Table 1 General machine and soil data of different implements (width app. 3 m, depth appr. 5 cm) at various adjustments, on silt soil (appr. 40% < 16 μm).

CONCLUSION

The defenite machine selection has to be made, dependent on soil type and crop rotation.
In Dutch areable farming, one may expect more and more powered implements, the more so as obstacle problems generally do not occur.
Simple mechanicle principles (f.i. rotation) are preferred above vibration and translation from point of views of wear and tear.
The machines offer possibilities for special situations (time missing for tillage sequence) and for "heavy duty" jobs like soil sterilisation.

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Extensive cereal production in minimum tillage as alternative form for landscape shaping

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Abstracts:

Because of many reasons former arable land lies fallow - almost exclusively in nice landscapeswith poor agricultural production conditions.
Instead of using shaping methods that cost money, our idea is, to practice an arable method offering a cultivated and shaped open landscape with changing aspects during the year. Our results show that it is possible to get a sufficient grain yield while producing extensively, that is no ploughing, no straw harvest, low mineral fertilizer level, no or only a few spraying and using suitable cereal (rye, barley, oats) and green crops (legumes,rape).

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In natural landscapes there is no need for any shaping its aspect. Questions of landscape shaping become actual when arable land is not cultivated any more. In W.Germany the amount of former farm land lying fallow increased from 220.000 ha in 1970 to about 300.000ha in 1974 and a pessimistic taxation of this development predicts for 1980 1- 1,8 Mio. ha fallow land in W. Germany. (6)
Reasons for this are known as

- the economical development that offers a better income in the industry than on farms
- unequal structure of farm land

- poor quality of the factors soil, water, land inclination a.s.o.

A similar development also takes place in other european countries (4). Though fallow land also shows some advantages, it is generally refused because of reasons like

- this development directly leads to some form of wood that in many regions is sufficient (>70%) and a recultivation than will become difficult.
- the unshaped aspect is not liked and has a negative influence on tourist traffic.

As most of the fallow land was former arable land, and different types of an extensive land use are not profitable and cause costs (1) we vote for an extensive agricultural method consisting in:

1. Cereal crop-rotations (barley, oats, rye) with and without cultivation every year
2. Minimum cultivation with a rotaseeder, that is direct-drilling and tilling the soil shallow but totally
3. No stubble cultivation, straw remains evenly distributed on the land
4. Nitrogen level is low but sufficient, 0-80 kg/ha depending from the kind and the chance of establishing a 'green crop'
5. P/K (MgO/CaO) fertilizer application to a cereal crop is relatively low (40,0 kg/ha K_2O/P_2O_5) according to the mineral bilance.
6. While using competitive cereal crops, spraying is confined to phenoxy-herbicides (1x)
7. Depending from agricultural manpower available, a "green fallow" of (66%) 50,30,25,0% in the rotation is planned.

Because of the extensivity, the operating costs of grain production become evidently lower, and we only need an average or low grain yield of 20-40 dt/ha to meet the costs (8) instead of risking a maximum yield while using a high level of intensity. A similar calculation concerning wheat production (2) supports our thesis. Beyond that, this cultivation method promises a very few charge of environment by erosion from sloped arable land (7). Some years ago one demanded an alternative form of land use for the "Schwäbische Alb", providing erosion control like pastures and avoiding the monotonous aspect of them (3). As fallow land often occurs on soils with evident deficiencies of limiting soil management and high yields, 3 different field tests were carried out on 2 typical poor sites of arable land (6).

[illegible]

[illegible]	[illegible] (... vom Schwarzwald)	[illegible]
Soil	[illegible] with ... percentage of limestone	[illegible]
pH-value in [illegible]	[illegible]	[illegible]
Ø (°C) temperature	7.9	[illegible]
Ø (mm) precipitation	700	[illegible]
Slope inclination %	slight (0-5)	[illegible]

Our questions were:

1. Which grain yield is possible under these production conditions on different poor sites to decide, whether one or the other extensive form of grain production is profitable or not?
2. Can a fallow in the rotation (old three-field-system) increase the grain yields?
3. Is it worth while establishing a green-crop - and which one - in the time between a winter and summer cereal crop or in the fallow years?
4. Does this cultivation method without the plough sufficiently fight a weed infestation (grass)?
5. What about the traversibility of these fields (for recreation uses) in the time between harvest and seed?

[illegible]

kg/ha	[illegible]	[illegible]	[illegible]	[illegible]
I [illegible]	[illegible]	[illegible]	[illegible]	[illegible]
60	[illegible]	33,4	[illegible]	
II 30	34,7	----	30,3	----
60	30,7	----	24,7	----
III 30	34,7	----	22,3	
60	30,7	----	26,7	
IV 30	----	63,1	----	
60	----	61,2	----	

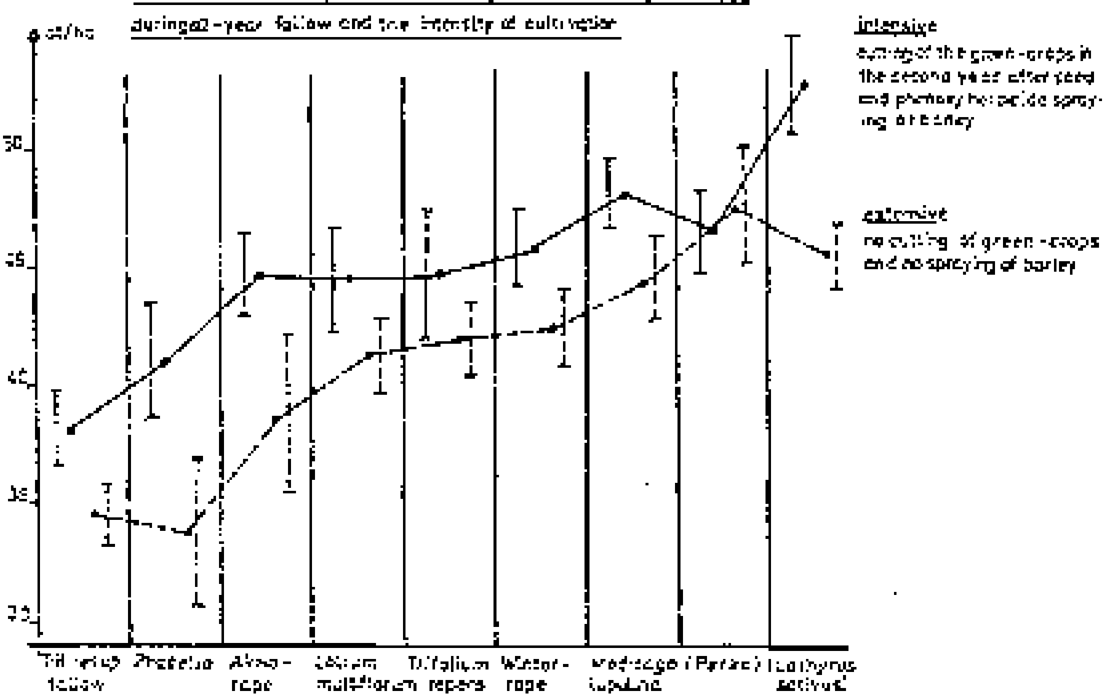
The 60 kg/ha N-level only lightely effects the corn yield of rye positively in 1974. The 60 kg/ha N-level even lowers the grain yield of barley. The reason of it is unknown. The fallow year without green crops, but weed infestation with thistles (1973), increased the grain yield of barley by about 15% in 1974.

[illegible]

kg/ha		[illegible]	[illegible]	[illegible]
I [illegible]	40	45,7	[illegible]	26,6
	70	54,5	51,4	[illegible]
II 8/7	40	[illegible]	[illegible]	[illegible]
	70	[illegible]	41,5	[illegible]
III 8/8 [illegible]	40	[illegible]	----	24,6
	70	[illegible]	----	27,2
IV 7/8 [illegible]	40	[illegible]	----	[illegible]
	70	[illegible]	----	[illegible]
V recultivation (fallow 10 y.)	70	----	28,9	[illegible]

On this site a relatively high nitrogen level increased the grain yields of oats and rye in each variant. Higher grain yields were obtained while cultivating the land every year after the plough instead of the rotary hoe. The reason of this can be seen in the fact, that on II deer grazed the rape green-crop totally (this was about 30 dt dry matter/ha) in autumn 1973. Another fact was grass infestation. It seems to become a problem (Apera spica venti, Agrostis ssp.)
This is why we vote for ploughing every two years on this site when a green-crop fails. Fitting in a fallow year, its effect on the grain yield of winter rye was most evident using the "Trifolium repens green-crop" instead of none. The high yield after a green fallow with Trifolium repens and the 70 kg/ha N-Level can -even on the long run- be more profitable than ploughing every year. Because of the possibility of a grass-infestation during a fallow year, the N-and humus accumulation, one should not miss the suitable white clover catch-crop on this site.-The recultivation of an over ten years old fallow (V) - using the rotaseeder and 70 kg N/ha showed a surprising yield of oats (29 dt/ha) in 1974.
In this first year after a long fallow period the field was clean from grass-weed and oats showed a very healthy aspect but the tillering was low. The following grain crop in this variant (rye 1975) had a low yield, may be be - cause of the increasing grass-infestation, N-immobilisation by straw(oats) and no P/K fertilization.

Tab. 4 Grain yields of barley (dt/ha) depending on different green-crops during a 2-year fallow and the intensity of cultivation



A two-year fallow with different green-crops showed distinct effects on the grain yields of barley. The in- tensive treatment showed -almost with no exception - higher yields. Best results we got after Medicago lup- lina. Very similar results were obtained with Trifolium repens, rape spec. and Lolium multiflorum. Perko and Lathyrus sativus are invalid because of there complete infestation by Atriplex patula.

Summarising we can state, that the catch-crops with a bad growth and competition in the second year showed lowest yields (Fallow, Phacelia, Akela-rape) and a phenoxy- herbicide spraying there had highest and significant ef- fects. In each case the grain yields after a catch-crop exeed these after a mere fallow with its higher weed in- festation.

The question of the need of an alternating ploughing, while predominantly using a rotaseeder for soil tillage and seeding in this form of an extensive cereal production seems to be depending on

- the type of weed infestation
- the competition effect of the cereal type
- the application of a competitive catch-crop in the "fallow year"

As far known, there is no need for ploughing while using winter-rape kinds as a very competitive catch-crop on a one year fallow or clover kinds on a two-year fallow. Even no spraying is needed in the first cultivation year after an old fallow on the sandy site.

It is evident that the straw mulch after the harvest im- proves the traversibility of fields. With this respect, a mere straw mulch without a green-crop in the time after harvest and bevor seed seems to be better.

So far our experiences with a new method of landscape - shaping. This was only practicable because of the new technology of direct-drilling with a rotaseeder. As to the grain yields achieved in our field tests, we can state that there are possibilities to meet the costs of a land- scape - shaping in this way.

The 7th Conference of the International Soil Tillage Research Organization, Sweden, 1976

DANISH EXPERIMENTS ON SOIL COMPACTION

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ABSTRACT

Soil compaction by traffic in spring has reduced the pore space and the air content in the upper 6-1o cm. The reductions are greatest after the first run over and after compaction under wet conditions.

A specific vertical pressure > o.7 kg/cm^2 has in many cases reduced the air content to lesser than 1o volume per cent. The compaction causes a reduction in the part of large pores (>3o µm) and the hydraulic conductivity decreases. Intensive traffic on wet soil has given considerable smaller yields of grain, whereas moderate traffic under ideal and dry conditions hasn't done any damage. In certain circumstances under dry conditions the compaction has even been useful.

The optimum pore space on the sandy loam soil is 41-44 volume per cent and on the silty loam soil 5o-54 volume per cent, while the optimum air content in both of the soils is 11-15 volume per cent.

SOILTYPES AND EXPERIMENTS

Experiments with soil compaction before sowing of barley in spring were carried out in the years 197o-1974 on sandy soil at Jyndevad, on sandy loam at Rønhave and on silty loam at Højer. The texture of the soils is shown in table 1.

Table 1 Analysis of the texture in the upper o-25 cm, per cent

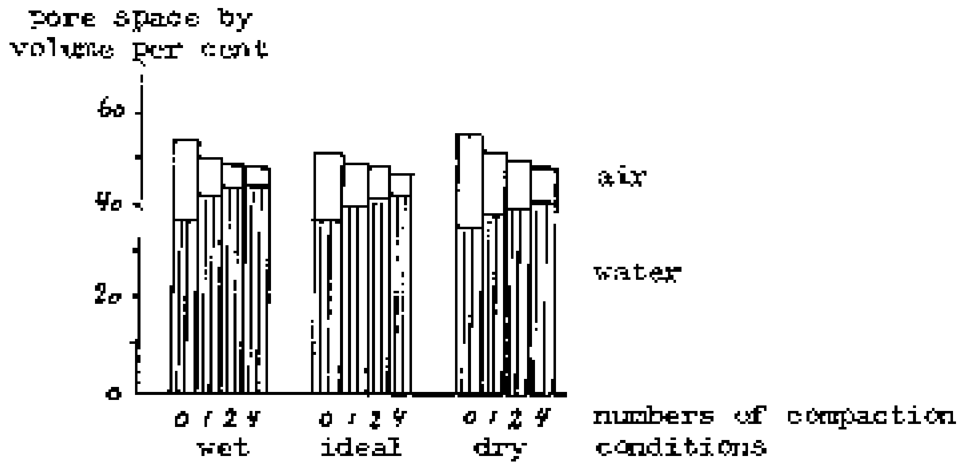
	Humus	Clay <o.oo2 mm	Silt o.oo2-o.o2 mm	Fine sand o.o2-o.2 mm	Coarse sand o.2-2.o mm
Jyndevad	1.8	3	2	18	75
Rønhave	2.1	13	17	49	19
Højer	2.2	13	13	7o	o

In the fields the soils were compacted with tractor wheels respectively o, 1, 2 and 4 times under wet, ideal and dry conditions. Experiments with different specific pressure are carried out in lysimeters on the same soil types as in the fields. The specific pressure has been respectively o, o.4, o.7 and 1.o kg/cm^2.

PORE SPACE, WATER AND AIR CONTENT

Figure 1 shows the content of pore, water and air of the silt loam soil immediately after compaction in spring. The traffic causes a reduction in the pore space and air content. The greatest changes occur after first run over. The total pore spaces in the upper 6-1o cm of the soils are shown in table 2. On the sandy soil the pore space is reduced from 51.4 volume per cent in the uncompacted soil to 39.7 per cent after 4 compactions, at the sandy loam from 42.3 to 36.5 per cent and on silt loam from 53.o to 45.7 volume per cent. A specific vertical pressure of 1.o kg/cm^2 has under wet and ideal conditions reduced the air content to lesser than 1o volume per cent on the loamy soils. o.7 kg/cm^2 has only in a few cases reduced the air content to lesser than lo volume per cent which is regarded as the lowest limit for air content in these soil types.

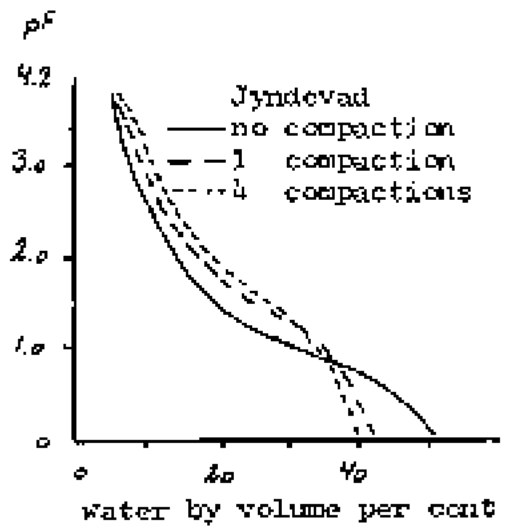
Figure 1 Pore space, water and air content in 6-lo cm depth after establishment in spring. Silt loam.

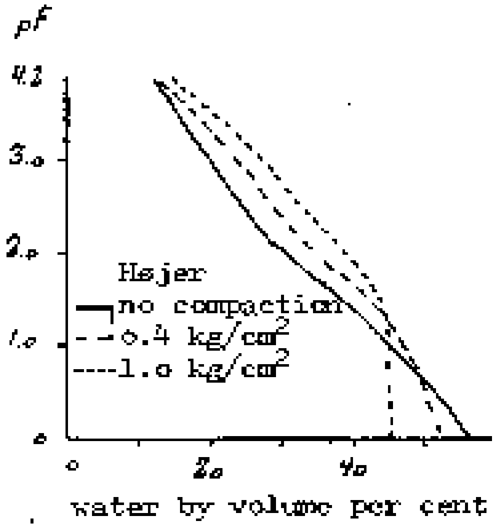


RETENTION CURVES AND PORE SIZE DISTRIBUTIONS

Retention curves from the field experiment on the sandy soil and from the lysimeter experiment with silty loam are shown in figure 2 and the pore size distributions are shown in table 2.

Figure 2 Retention curves for sandy soil (Jyndevad) and silty loam (Højer)





On the sandy soil the part of large pores are reduced from 37.4 volume per cent in uncompacted soil to 21.7 volume per cent after 4 compactions. At the same time the part of medium pores are increased from 9.9 to 13.o volume per cent which means that the water household is improved because the part of small pores are almost identical. On the sandy loam the part of coarse pores are decreased from 12.4 to 6.3 volume per cent and on the silty loam from 14.4 to 3.9 volume per cent.

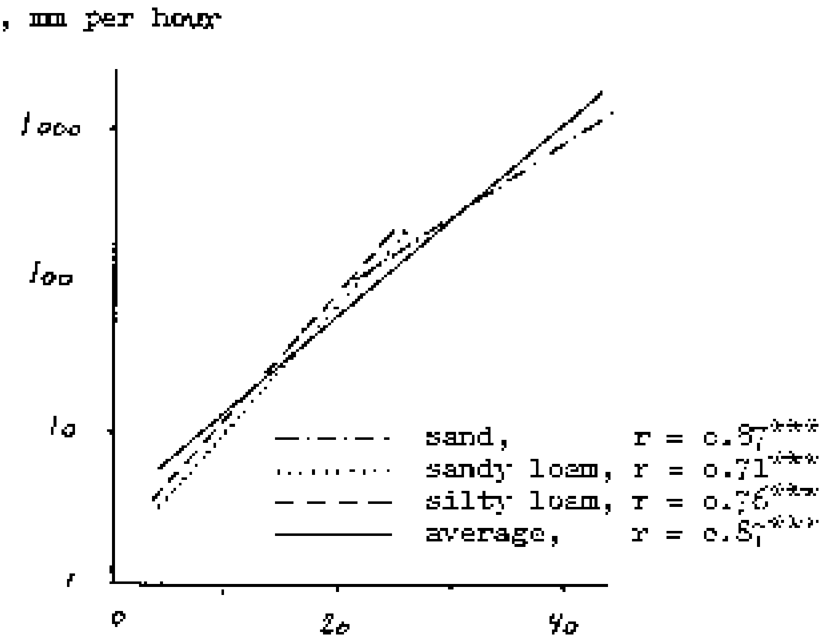
Table 2 Pore size distribution, per cent by volume

	Pore size, µm			
	large	medium	small	Pore
Jyndevad (sand)	> 3o	3o–o.2	< o.2	volume
Uncompacted	37.4	9.9	4.1	51.4
1 compaction	24.6	12.5	4.8	41.9
4 compactions	21.7	13.o	5.o	39.7
Rønhave (sandy loam)				
Uncompacted	12.4	19.o	1o.9	42.3
1 compaction	12.1	18.5	11.1	41.7
4 compactions	6.3	17.3	12.9	36.5
Højer (silty loam)				
Uncompacted	14.4	29.2	9.4	53.o
1 compaction	6.o	31.3	1o.4	47.7
4 compactions	3.9	31.o	1o.8	45.7

HYDRAULIC CONDUCTIVITY FOR SATURATED SOIL

Hydraulic conductivity for saturated soil (kf) is dependent on the part of large pores as shown in figure 3 where the results of measuring from the three soils are shown. Small changes in the part of large pores mean great changes in the conductivity.

Figure 3 The relations between the part of coarse pores and hydraulic conductivity for saturated soil



THE YIELDS OF GRAIN

The influences of the compactions on the yields of barley are shown in table 3 which shows the averages of the years. On an average one compaction hasn't been injurious to any of the soils. Two compactions have reduced the yields on the loamy soils under wet and ideal conditions and four compactions have reduced the yields on all three soil types under wet and ideal conditions whereas the injury under dry conditions was minimal.

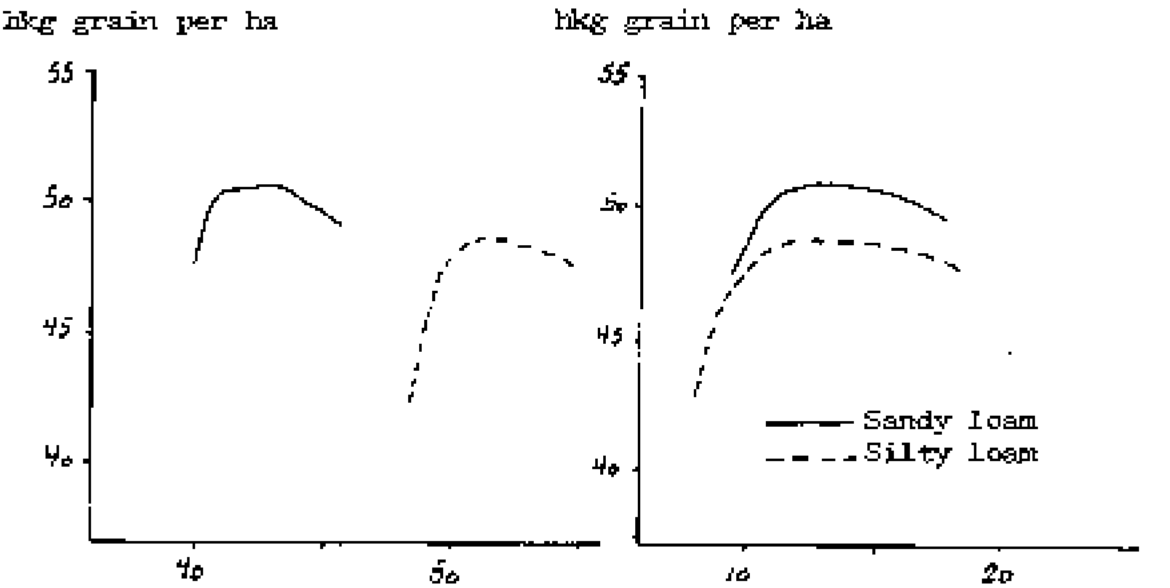
Two compactions under dry conditions on the loamy soils have been useful. In years with moisty growing seasons (May–June) there are found considerably reductions in the yields after compaction.

Some years with dry summer the yields are increased after compaction. The relations between yields, pore space and air content are shown in figure 4.

Table 3 Yields in hkg grain per hectare (barley)

Conditions of wetness	numbers of compactions	Jyndevad sand	Ronhave Sandy loam	Højer silty loam
wet	o	30.8	49.7	49.1
	1	31.3	50.4	48.9
	2	30.6	48.3	45.3
	4	29.0	45.5	36.6
	LSD_{95}	-	3.4	2.7
dry	o	30.4	50.6	47.0
	1	30.4	51.0	48.9
	2	30.1	52.3	49.4
	4	29.8	49.1	47.4
	LSD_{95}	-	1.9	-

Figure 4 Relation between yield, pore space and air content



The optimum pore space is 41–44 volume per cent in the sandy loam and 50–54 volume per cent in the silty loam. The optimum air content in both of the soils is 11–15 volume per cent.

It hasn't been possible to record some relations between yields, pore space and air content in the sandy soil because periods of draught in the growing seasons most years have limited the yields.

REFERENCE:

Rasmussen, K.J. (1976) Soil Compaction by traffic in spring.
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II. Soil physical measurements
Tidsskr. for Planteavl (In press)
(Danish with Eng. subtitle)

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COMPACTION AND ROOT GROWTH IN RELATION TO CULTIVATION

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ABSTRACT

Simplified methods of cultivation, especially direct drilling, usually increase soil compaction. An understanding of the effects of mechanical resistance on root penetration thus assists in interpreting responses of crops to different systems of cultivation.

If roots experience external pressures greater than a small fraction of a bar their rate of extension is much reduced and their branching can also be modified. Adequate root growth thus requires the presence of sufficient continuous pores which roots can penetrate freely or expand while resisting only small pressures.

The greater compaction of undisturbed soil may not result in a corresponding reduction in these avenues for root extension, but relationships can vary greatly depending on soil and climate.

Introduction

Traditionally the cultivation of soil served two main purposes, to control weeds and to provide a suitable environment for the growth of plant roots. These needs had been recognised before the dawn of the Christian era and until recent decades there was little change in the basic methods used in Western agriculture, namely ploughing followed by secondary operations to create a seed-bed. These operations appeared to be such an essential part of good husbandry that except in those areas where elaborate tillage gave rise to problems, for example because of soil erosion, there was little incentive to study the functions they served. Thus, in our country the first detailed experiments on the effects of cultivation on crop growth in the absence of weeds did not commence until the 1920s (see *Keen and Russell*, 1937); the situation was broadly similar in other areas. It occasioned much surprise when these investigations showed that, in the absence of weeds, the disturbance of the soil to the extent formerly practised was unnecessary. But this information was of little practical importance; cultivation was essential for weed control.

More recently the development of herbicides caused the situation to change dramatically. Much reduced cultivation is now possible - even direct drilling (zero cultivation) can be successful in many, though not all, circumstances. If full advantage is to be gained from these new opportunities, without undue risk, a much fuller understanding is required of how plant growth is affected by the changes in soil physical conditions which occur when cultivation is suspended. Of these one of the most obvious, though not necessarily the most important, is the greater compaction of the soil. Thus, in the first part of this paper we consider some of the basic effects of compacting the soil on root growth. Subsequently we refer to these responses in the broader context of crop growth under different systems of cultivation.

Compaction and the porosity of the soil

The presence of a sufficient number of pores which drain freely under gravity, i. e. diameters greater than 60-100 μm, is a prime requirement equally for drainage in wet conditions, for aeration and for root growth. Some introductory comment on the effects of compaction on pore space is therefore relevant. There is no easier way of reducing the volume of soil occupied by pores, especially the larger ones, than by compression - for example, by smearing surfaces with implements or by the traffic of machinery or animals, especially when the moisture content is high. The magnitude of change which can occur is indicated by Schuurman's (1965) observation that when the bulk density of soil rises from 1.2 to 1.5 g cm^{-3} the total volume of pores greater than 100 μm decreases from 17.4 to 1.6% (Fig 1). But there is no simple relationship between the pressure to which soil is subjected and the extent to which pore space is affected. Soil "strength" is influenced both by water content and by the stability of the pores.

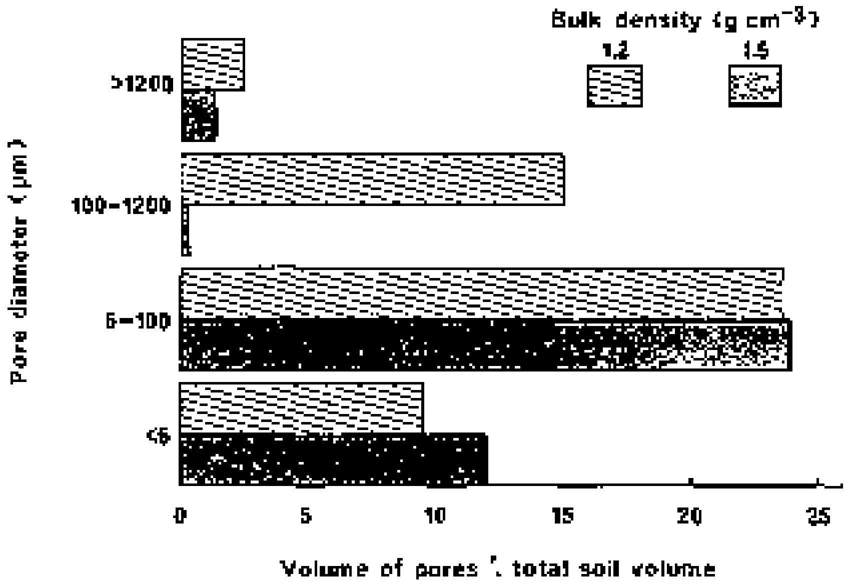

FIGURE 1

Effect of compaction on pore size distribution in a sand with 2.1% humus. (Derived from Schuurman, 1965)

Compaction and root growth - mechanical impedance

The reduction in the volume of the larger pores in soil, to which compaction can lead, can affect root growth in many ways. Of these mechanical impedance is mainly considered here but it is important to bear in mind that if compaction increases the aeration of the soil may also be affected. Because oxygen diffuses in the gas phase some 10,000 times more rapidly than in solution, the aeration of the soil depends largely on an adequate continuity of air-filled pores and if the rate at which oxygen is used in respiration by roots and micro-organisms is relatively high the concentration of oxygen may sometimes sink to zero only 2 mm from air-filled pores (Greenwood, 1969). Thus, because of the effects on pore space in compact soils, plants growing in soil may simultaneously be exposed to anaerobic conditions and mechanical impedance. Quantitative relationships between mechanical forces and root growth are therefore seen most clearly in artificial systems where mechanical forces, such as roots experience in the soil can be simulated but other factors are maintained constant. The majority of the results now to be discussed were obtained in this way.

The response of roots to mechanical stress was little studied until the last few decades despite the fact that before the end of the last century Pfeffer (1893) had shown that when rigidly confined living roots could exert considerable pressures, perhaps 10 bar. The minimum pressures which restrict root penetration are of greater relevance to crop growth and it was not until after 1950 that Gill and Miller (1956) made the first quantitative study of this question. Another important observation was made by Wiersum (1957); he showed that roots are unable to decrease in diameter to penetrate pores smaller than themselves. It is now well established that if roots have to resist pressures of more than a small fraction of a bar to expand pores their rate of elongation may be considerably reduced. In barley (Hordeum vulgare) the length of roots is reduced by a fifth when the external pressure is barely half an atmosphere and pressures as low as 0.2 bar can lead to considerable stunting (Fig 2). Although inter-specific differences occur, all experiments in which the pressures which roots experience have been directly measured show a considerable reduction in elongation if the pressure resisting penetration is 0.5 bar or less. Growth can, however, proceed slowly against considerably higher pressures.

The branching pattern of roots is also affected by external pressure. Laterals are closer together and their length may be much increased if the pores in the rooting medium permit them, but not axes, to penetrate freely. Sometimes this can lead to a root system consisting mainly of laterals born on stunted axes (Fig 3). These root systems are very shallow - the total depth with cereals being little more than 5 cm after 3 weeks growth. Under field conditions such root systems suffer obvious disadvantage through a restricted supply of water and nutrients. But if they are protected from these stresses the weight of the plant and the uptake of nutrients may not be impaired (Russell and Goss, 1974).

The mechanism which causes the extension of roots to be so much affected by small pressures is not yet understood but it seems that there may be effects on hormonal control mechanisms inthe root meristem and on fine structure (Russell and Goss, 1974).

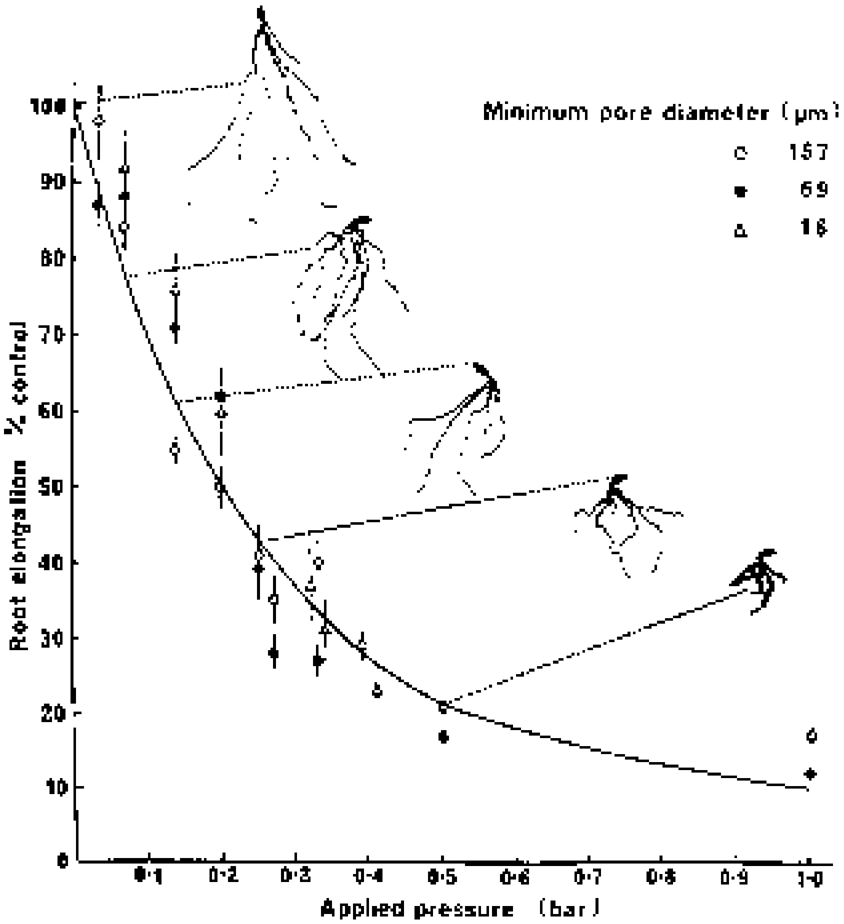

FIGURE 2

Effect of applied pressure on the rate of elongation of seminal axes of barley (Hordeum vulgare). Plants 7 days old grown in beds of ballotini of varying pore diameter.

Irrespective, however, of the exact mechanism by which roots respond to mechanical impedance, the conditions necessary for their penetration of the soil are obvious, namely the presence of sufficient continuous pores which roots can penetrate freely or which they can expand while resisting only very low pressures.

Cultivation and root penetration

The sensitivity of roots to small mechanical forces might suggest that growth would usually be much restricted unless the soil had been loosened by cultivation. Undoubtedly there are circumstances when the disturbance of the soil is essential, but it can also create restrictions to penetration by roots. It is instructive from this viewpoint to consider why land maintained under permanent grass for many years may provide superior conditions for root growth than after careful arable cultivation. The detailed nature of changes varies with many factors but some quite widely applicable generalizations are possible. The stability of the pore regime is typically greater under grassland; within a year of ploughing it may decrease markedly though the total organic

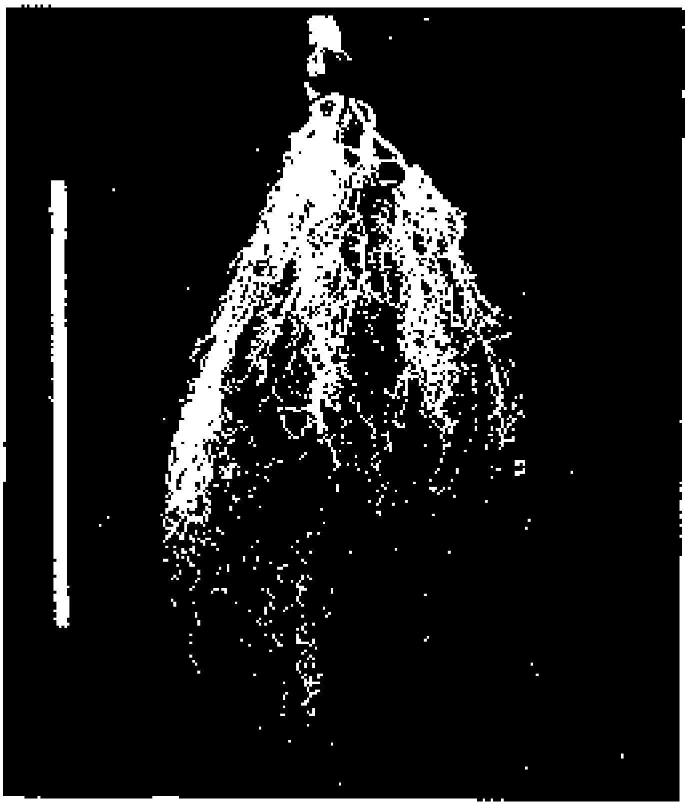

FIGURE 3

Root system of barley plant 3 weeks old grown in rigid pores 150 μm in diameter. Axes but not laterals were impeded. (Scale bar = 5 cm)

matter in the soil is little altered (Low and Stuart, 1974). This seems to be because stability depends largely on relatively labile organic matter produced by micro-organisms from root exudates or dead roots; the disturbance of the soil can much hasten the breakdown of these products. Moreover, under permanent grassland channels left by burrowing organisms, the decay of old roots are preserved as well as planes of weakness caused by the shrinking of the soil. They can be of major importance both for drainage and root penetration.

There is now much evidence that soil which has been direct-drilled for several years can develop these characteristics to some degree, thus becoming intermediate between land under permanent arable cultivation and permanent grassland (Baeumer and Bakermans, 1973). Considerable increases in the earthworm population have also been observed (Schwerdtle, 1969; Cannell and Ellis, 1976). The extent to which these changes offsets the greater compaction of the soil caused by the abandonment of cultivation can vary depending both on soil type and weather. In unstable soil the need for periodic deep cultivation may not be eliminated in some climates. But definite benefits can occur in other circumstances. On some heavy clay soils the preservation of planes of weakness which permit root penetration can be of considerable importance.

Moreover, the abandonment of cultivation on such soils may sometimes have the additional advantage of eliminating the risk of serious compaction when carried out under unfavourable conditions.

Finally, attention is drawn to the unavoidable limitations of all simple physical measurements of the characteristics of the bulk soil for predicting the response of root systems to mechanical stress, especially in soils with massive structural units. Taylor et al (1966) have obtained useful empirical correlations between root penetration and soil resistance to penetrometers in uniform soil. In soils with large structural units there may be little relationship. Root penetration then can occur largely through the intervening planes of weakness rather than through the bulk soil.

Current interest in simplified methods of cultivation is a stimulus to seeking a fuller understanding of the response of roots to soil physical conditions, a subject which calls for the joint endeavours of plant physiologists and soil physicists.

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TILLAGE PERFORMANCE AND DESIGN THEORIES OF ROTARY TINE-BLADES FOR ASIAN PADDY RICE CULTIVATION

by Jun Sakai

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ABSTRACT

The tillage mechanism of rotating tine-blades driven by a tractor has greatly increased as a main tillage equipment in the mechanized farming of paddy rice cultivation in Japan. These machines are called "Rotary Power Tiller" and "Rotary Tractor".

In order to minimize tillage resistance and make them fit to the field and cultivation conditions of Asian paddy rice farming, unique rotary tine-blades of rotary tillers have been developed.

Main specifications and dimensions for designing rotary tine-blades are obtained through theoretical calculations.

1. BACKGROUND OF ROTARY TILLAGE FOR PADDY RICE CULTIVATION

The tractor has appeared after utilization of animal powers on the farm. All kinds of field equipments for draft animals have been modified so as to be pulled by tractors. Among them, there have been some rotating tools like disk plows and harrows, etc. In addition, the special mechanism of rotating tine-blades powered by the tractor engine has been developed in Europe.

Western countries consist of mainly field farming. Their soil tillage is usually performed by plows, harrows, cultivators and so on drafted by tractors. Powered rotating mechanism is partly used.

Asian farming regions consist of mainly paddy rice cultivation, and their mechanical tillage has a different development pattern from Western one. The traditional tillage equipments of draft animals have a tendency to be replaced by the rotating mechanism driven by tractors, particularly in irrigated area.

In Japan, 300,000 to 500,000 units of hand tractors are produced every year. About a half of these are the hand tractors coupled with rotary tillers. These are called "Rotary Power Tiller". In 1975, Japan produced about 200,000 units of riding tractors. About 75 % of these tractors were coupled with rotary tillers as a standard type called "Rotary Tractor". In Japan, there was 4,521,000 hectare of arable land (field and paddy field) in 1974. Of this 3,209,000 hectare is paddy rice field. More than 95 % of paddy field tillage is considered to be carried out by rotary tillers.

2. PADDY RICE CULTIVATION SYSTEM AND ROTARY TILLAGE

As a rule, rice cultivation starts in the biginning of rainy season. The cultivation is divided into two systems, namely, direct sowing and transplanting system. The former is applied in very limited area (1 % or so, 1974 in Japan), while the latter is more popular and standard cultivation method in Japan and other Asian countries. The rotary tillage for the transplanting system of paddy rice cultivation is as following;

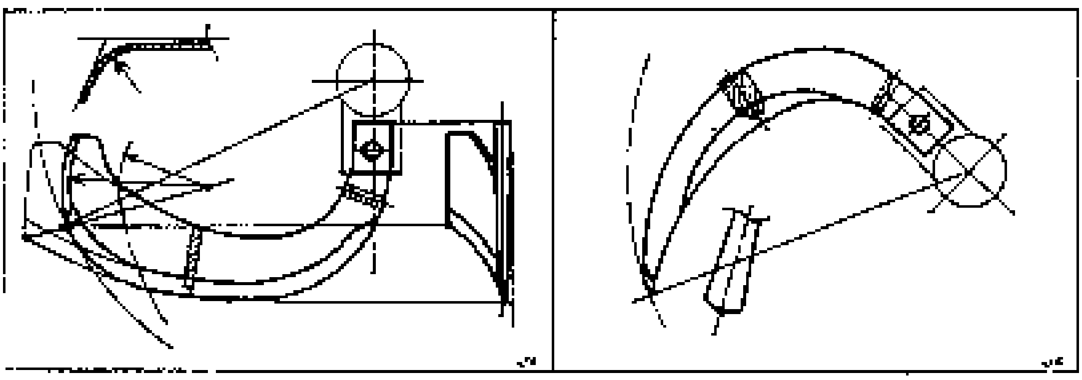
① Seedbeds can be easily prepared in earlier season with small amount of water, because the size of a seedbed is 1/10th to 1/20th of paddy rice field to be transplanted. The rotary tiller produces the seedbed of fine harrowing.

② After seedbed preparation, the field has to be prepared (puddled) with enough amount of water for transplantation. The soil conditions requested after puddling are of flat level mud surface and uniform soft tilth that gives minimized pain to the fingers of transplanting farmers and also has enough consistency to hold the young plants. Tillage by the rotary tiller is easier to keep soil surface flat. With one or two passes of the rotary tiller, in general, a suitable and uniform harrowing effects can be expected.

③ Perfect puddling work is expected to remove and/or kill weeds. This puddling has to be done within one-day-before transplanting. Then, farmers transplant the young rice plants which have a better growing phase than weeds in the soil. A well designed rotary tiller can cut weeds and combine them into the muddy soil.

④ Although the working efficiency (time and fuel consumption) of the rotary tillage is lower than that of only plow-tillage, the total efficiency including harrowing and puddling of it is considered to be almost equal or better. In other words, it is more convenient than that of plow and harrow utilization for preparatory tillage of paddy rice transplanting system.

These are the reasons why the rotary tillage has greatly increased in Asian paddy rice farming area. The shapes and design theories of Asian rotary tine-blades may show some difference from general rotary tine-blades of Western type. Fig. 1 shows examples of Japanese rotary blade and tine respectively. The hook-tine as shown in Fig. 1 is used scarcely for paddy rice cultivation, because weeds are apt to entwine on it easily.



Rotary Blade　　　　Rotary Hook Tine

Fig. 1 Examples of Japanese rotary blade and tine.

3. TILLAGE DEPTH AND RADIUS OF ROTARY TINE-BLADE

In the time of animal plowing before world war II, general plowing depth of the paddy rice field in Japan was 9 to 10 cm. The average yield of rough rice was 3.5 to 4.3 tons per hectare in 1935 to 1940.

The national necessity of higher production of rice promoted the farming technology of deeper tillage and utilization of more chemicals and fertilizer. The farmers required a machine performance for tillage depth changed from 10 cm to 15 cm, if possible 18 cm. The average yield became 4.5 to 5.2 tons per hectare in 1955 to 1960.

In the period 1960 to 1976, this has changed again from 18 cm to the range of 12 to 14 cm, because of changing technology of rice cultivation and development of transplanting machines.

In old times, it was a common system to give additional fertilizer once or twice after the base fertilizer. However, recent 10 to 15 years, farmers in Japan became to give additional fertilizer at least three to four times, observing the growing condition of rice plants, thus making paddy rice roots grow shallow in the shallow tilth. To control the soil and water of shallower tilth is easier than to do those of deep tilth.

In old times, young rice plants grown at least 20 to 25 cm were used for transplanting by manual labour. Due to the advancement of indoor growing system of rice seeds and greater capacity of transplanter machines, younger plants are used for transplanting. Shallow tillage is also accepted by the farmers to prepare flat and nice soil surface that will give stable machine travel and accurate transplanting work. The average yield of rough rice in Japan was 5.0 tons per hectare, 1973, and 5.9 tons per hectare, 1974.

The design equation to get the conceptional radius, r, of the tine-blades is;

$$r = H + a_1$$

where H = the maximum depth of tillage,

a_1 = the bottom radius of the transmission case of the tiller.

Actual values of a_1 in the case of 7 to 14 ps hand tractors and 10 to 15 ps riding tractors for small scale farmings are 9 cm or so. Adding 12 to 14 cm of H to a_1, common size of rotary tine-blade radius for Japanese rice cultivation is 20 to 22 cm.

This means that the conceptional capacity of tillage depth of rotary tillers can be estimated from the dimensions of its side view.

4. DETERMINATION OF RPM

The tillage force τ kg, produced at the tip of the rotating tine-blade is calculated by;

$$\tau = \frac{71620\ Ne\ \eta e}{r\ n}$$

where Ne = engine ps,
ηe = mechanical transmission efficiency,
r = radius of tine-blade, cm,
n = rpm of rotary axle.

Higher revolution of the tine-blade will produce higher effects of harrowing and smaller tillage force τ kg. This means that higher revolution is easier to produce lack of tillage force, and slowdown of engine rpm or shallower depth of tillage.

Slower revolution of the tine-blade will have rough harrowing and strong tillage τ kg, which has a capacity of deeper tillage. However, if such bigger force τ kg grows over the adhesion and husking capacity of drive-wheels to the ground, the tractor will lose its stable travel. In other words, the tractor will have much slip-forward or spring-forward phenomenon.

Basing on these consepts, the minimum valve of tine-blade rpm has to be decided (calculated) so as to have no spring-forward phenomenon, under the condition of full horsepower operation of the tractor.

The pressing-forward force of tine-blades is changeable depending on the "Radial Suction Force" (named by the auther) of rotary tine-blades of the tiller, as shown in Fig. 2.

Maximum rpm of the rotary axle is decided from the harrowing requirement of farmers and tractor engine capacity, etc. Two to four shift gearings of rotary axle rpm are adopted in the range of minimum to maximum rpm.

In general, the tine-blade rpm of rotary tillers in the case of Asian paddy rice cultivation is in the range of 150 to 400 rpm.

The lowest revolution of the tine-blade is also important to discuss the strength of machine parts.

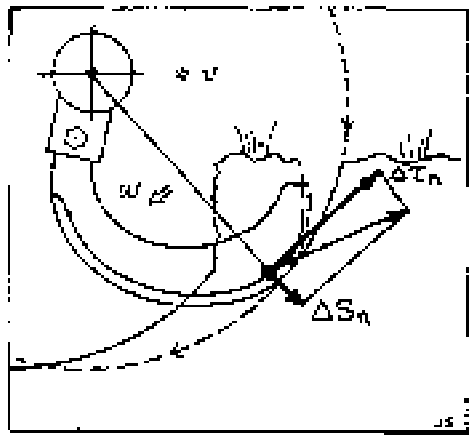


Fig. 2

5. NUMBER OF TINE-BLADES AND TILLAGE WIDTH

The tillage width of a rotary tiller has to be at least the same as or bigger than the outer width of both standard drive wheels. The engine horsepower of the rotary tractors and rotary power tillers is carefully selected with this condition.

The smaller number of tine-blades on a rotary axle is advantageous to having smaller tillage resistence.

As shown in Fig. 3, general value of tine-blade holder interval c is 40 to 50 mm, because hook-tines may be mounted on the same holders for the blades. Actual design dimension of blade width c'= c - 5 to 10 mm. Total tillage width of a rotary tiller can not be the value of total number of tine-blades times c. As shown in Fig. 4, there are some rotating faces where two blades are rotating on the rotary axle.

Thus, common relation of total tillage width w and total number of tine-blades b is;

$$b \doteqdot w \ / \ 37.5 \text{ to } 40$$

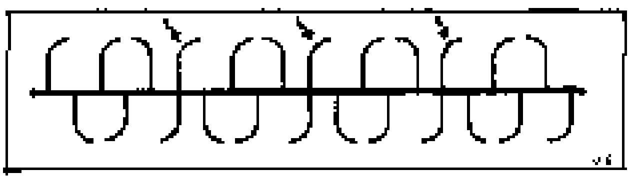


Fig. 4

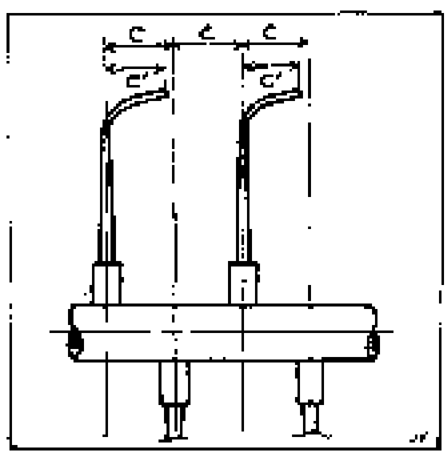


Fig. 3

6. KNIFE EDGE-CURVE OF ROTARY BLADE

When rainy season comes in late spring in countries of temperate zone, or after dry season in tropical countries, weeds start to grow in the fields. Also, there is straw, stubbles and grains of previous crop on the fields which have to be tilled and puddled.

Therefore, it is one of the fundamental design elements for the rotary blade to have an optimum knife edge-curve, in order to avoid the entwining of straw and weed.

In order to use the slip-cut force " $F \cos \delta$ " of weed and straw as shown in Fig. 5, a knife edge-curve is designed so as to have optimum "edge-curve angle" α, hairaku-kaku in Japanese, that is considered to be in the range of 55° to 67.5° in normal condition.

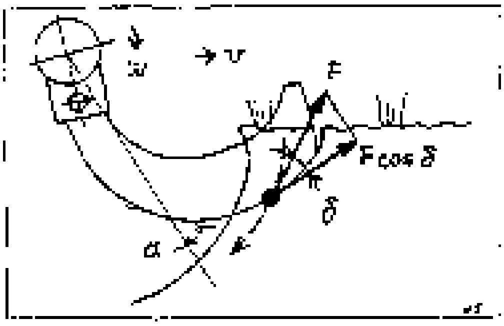


Fig. 5

Larger angle than 67.5° produces excess tillage resistance, and smaller angle than 55° produces poor grass-removing effect, resulting in the possibility of grass coiling to the rotary blades and axle.

The design equation of knife edge-curves is a kind of spiral curve equation as follows;

$$r_n = r_o \sin^{\frac{1}{k}} \alpha_o \sin^{-\frac{1}{k}} (\alpha_o + k\,\theta)$$

where r_n = calculated radius in polar coordinate, mm,
r_o = radius on the starting tip point of θ=0, mm,
α_o = edge-curve angle on the starting point of θ=0, degree,
$\theta°$ = changing degree in polar coordinate, every 10°,
k = constant to determine the increasing characteristics of the edge-curve angle, selected by a designer, 1/18 is recommended.

7. SCOOP ANGLE OF TIP SIDELONG PORTION, β_1

The sidelong portion is designed so as to have no pressing phenomenon of its outside surface to the soil.

β_1 in Fig. 6 is "Scoop Angle", haikaku in Japanese. This is the angle between radius direction and the outside surface of the tip sidelong portion.

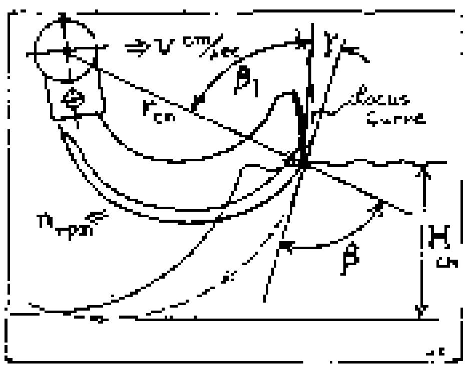


Fig. 6

$$\beta_1 = \beta - \gamma$$

where β = the angle between radius direction and the tangential line of the locus curve,

$$\beta = \cos^{-1} \frac{30v}{r} \sqrt{\frac{H(2r-H)}{(30v)^2 - 60\pi n v(r-H) + (rn\pi)^2}}$$

γ = relief angle. (refer to Fig. 6)

γ controls the turning and throwing back effects of the blade to soil clods. Bigger relief angle means smaller angle of β_1, and produces stronger turning and throwing back effects.

Actual scoop angle β_1 for Asian farmings is;

80° to 75° - - hard soil condition
75° to 65° - - common soil condition
65° to 50° - - soft soil condition

} in the case of single-edged blade.

The rotary blade of wide range use is designed to be 75° to 80° of β_1 at the lower part of its sidelong portion, and about 60° of β_1 at the higher part of the sidelong portion.
The actual measurement of β_1 for a given rotary blade will give a hint on the soil condition suitable to the rotary blade.

8. SECTIONAL SHAPE OF STRAIGHT KNIFE PORTION

The sectional shape of straight knife portion of common blades made in Japan is a double-edged knife of wedge type. When the double-edged knife cut vertically into the soil, the knife edge compresses the soil of untilled side, producing big tillage resistance.
A single-edged knife of equal thickness section or slightly reverse wedge type section produces smaller tillage resistance than that of a double-edged knife.

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"TILLAGE FOR DRY ANNUAL CROPS IN THE HUMID TROPICS"

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ABSTRACT

To investigate the possibility of arable cropping in the humid tropics a trial was set up on a sandy loam soil with emphasis on tillage. Three tillage systems were compared: rotavating, ploughing and minimum tillage. On all occasions ploughing gave the highest yield, and minimum tillage the lowest. Rotavating was positioned in between. Possibly yield differences arise from differences in weedgrowth. There were no differences observed in a number of physical data and in organic matter content. There was no indication from these measurements that soil fertility changed in this three year test period.

Introduction

Continuous dry cropping is not well known in Surinam, a country in the humid tropics with a rather evenly distributed rainfall of 2200 mm a year. On the coastal clay soils rice is the most important crop while on the inland soils dry annual crops are grown in a "shifting cultivation" system. The coastal clay soils are less suited for growing dry annual crops due to the small number of workable days and high drainage costs. (Fortunier) The loamy sand and sandy loam inland soils are more suited for growing these crops. The number of days with suitable weather for fieldwork is much higher and the costs of drainage can be neglected. A disadvantage of these inland soils is the low fertility. Shifting cultivation is a useful system for permanent soil use with only human labour (Nye & Greenland; Watters). A mixture of different crops is grown on small plots which are used only for a short period. Therefore a relatively large area is required for a small quantity of products. When more advanced techniques like e.g. the use of fertilizers, pesticides, and more effective equipment are accepted, it should be possible to utilize soil and labour resources more efficiently, and to produce a marketable surplus of crops. Therefore a trial with the emphasis on tillage was set up on an inland sandy loam soil with the aim to investigate:

1. the possibilities of continuously growing annual crops on sandy loam soils, under the prevailing conditions.
2. tillage systems for the crops involved.
3. the response of crops, weeds and soil to these systems.

In Surinam, like in other developing countries, there is a shortage of crops like maize, sorghum, soybeans, cowpea and peanut. These crops were therefore included in the experiment.

Methodes and materials

Before the experiment could start, the land had to be cleared from forest. The trees were pushed down by a tree pusher mounted on a caterpillar dozer. After some drying the trees were pushed together and burned. The rests were moved to the sides of the field. To promote decomposition of rests of wood and of stumps in the soil a cover and green manure crop kudzu (Pueraria phaseoloides (Roxb.) Benth.) was sown. After about two years this crop was mown with a slasher and ploughed into the soil with a disc plough. After ploughing rests of hard wood were removed, a seedbed was prepared by a disc harrow and the first crop was sown. To level the surface and to have an opportunity to dig out rests of wood and stumps and to get an idea of the quality of the field this treatment was repeated three times with the crops maize, cowpea and sorghum successively. After this year the experiment was set up in his definite form.
Three quite different tillage systems have been studied:

1. Intensive tillage with a rotavator to a depth of 15 cm, which produces a fine and smooth seedbed in a single pass. The weeds are thoroughly mixed in the soil.
2. Normal tillage with a 3 disc plough to a depth of 20 cm, followed by one passage of a roterra powered harrow, which produces a fine seedbed. With this system most of the weeds are buried.
3. Minimum tillage with a rotavator to a depth of 5 cm which produces a fine seedbed. All the organic material from the previous crop and the weeds is mixed in this thin layer.

On this experimental field crops can be grown the whole year round (almost constant daylength and temperature, rather evenly distributed rainfall and enough workable days for tillage, crop production and harvesting) so that immediately after a crop had been harvested the stubbles of the previous crop were slashed if necessary and tillage was carried out. The same tillage system was used for all crops.
The crops were rotated: after a cereal a legume crop followed and after a legume a cereal. The whole field, an area of 1.36 ha, was sown to one crop at one time. The first two crops were sown with a pneumatic spacing drill immediately after tillage, but to get a chance

to destroy seedweeds (inclusive germinated seeds of the previous crop) a tillage operation with the powered harrow was introduced about 14 days after the main tillage operation and sowing delayed accordingly.
In this way many seedweeds were destroyed. If the weather was rather dry weeding was done by handhoeing or hoeing by a tractor drawn hoeing machine. If weather conditions were wet chemically weeding with gramoxone, sprayed under a cap, was more successful. If necessary pests and diseases were controlled by chemicals. Owing to the high rainfall and the small adsorption capacity of the soil fertilizing was done two or three times. The quantities of fertilizer applied are listed in Table 1.
Harvesting the crops proved to be rather difficult because handharvesting took too much time; when the crop is ripe, it should be harvested within a few days, especially when the weather conditions are wet, because of rapid infestation by fungi. For mechanical harvest the crop varieties were more or less unsuited, but except for maize a solution was found. Harvest losses were determined and taken into account for yield determination.

Table 1. Quantities of fertilizer applied for the different crops. (kg/ha)

Crop	N	P_2O_5	K_2O	Ca	Period of growth
cowpea	60	60	60		17/1 - 29/3 /74
maize	72	60	180	700	3/4 - 3/8 /74
peanut	20	70	70		24/8 - 30/11 /74
sorghum	97	52	84		30/12- 11/4 /75
soybeans	20	60	60		14/5 - 4/9 /75
maize	100	30	85	1100	10/9 - 15/1 /75

The soil of the experimental field was a sandy loam. The subsoil was heavier then the topsoil (Table 2) This soil had a good physical condition. Water in dry periods was generally sufficient due to the clay content. As the clay mineral was kaolonite the adsorption capacity of plant nutritive minerals was minimal.

Table 2. Granular compositon

	% w/w			
depth (cm)	< 2μ	2-53 μ	53-2000 μ	> 2000μ
5-10	19.5	3.2	77.0	3.0
30-35	32.3	2.4	65.3	4.5
50-55	20.4	3.3	65.3	5.5

Measurements

Of every crop the yield per plot was determined. Moreover some measurements on crop development were made,as plant density after emergence and at harvest time, and sometimes plantheight at harvest time.

During crop growth and at harvest time estimations were made of weedgrowth.

On three places in the experimental field soil samples were taken from two depths i.e. the layer of 10-15 cm and of 20-25 cm. These soil samples were used for the determination of: 1. pore space, 2. aircontent at field capacity, 3. watercontent at field capacity and 4. organic matter content.

Results

In general the crop yields were good. It appeared that the average yields of ploughing were always highest and of minimum tillage lowest, while rotavating had a position in between (table 3). Yields as a percentage of the average were of ploughing: 110, rotavating: 102 and minimum tillage: 89.

Table 3. Crop yield(kg/ha; 12% moisture w.b.) and tillage systems.

crop	rotavating	ploughing	minimum tillage	average	S.E.
cowpea	726	836	596	722	130
maize	2728	2978	2414	2707	309
peanut	1901	1947	1675	1841	222
sorghum	2734	3032	2513	2760	326
soybeans	1465	1517	1155	1379	219
maize	2537	2900	2429	2623	225

The differences in yields of the different tillage systems cannot be explained by differences in pore space, air content or water content at field capacity. The differences in the organic matter content, which was measured according to the Walkley & Black method, are also insufficient to account for the yield differences.(Table 4)

	rotavating		ploughing		minimum tillage	
Depth (cm)	10-15	20-25	10-15	20-25	10-15	20-25
Pore space% v/v	48.5	48.6	47.5	46.0	49.1	48.3
Air cont.at pF2 % v/v	24.2	24.8	23.7	24.7	24.6	24.7
Water cont. at pF2 % w/w	13.2	17.8	17.4	17.2	16.7	17.8
Org. matt. cont. % w/w	2.55	2.39	2.47	2.51	2.49	2.39

Weedgrowth may also affect yield. It seemed that in the beginning the weedgrowth on the ploughed plots was poorest and on the minimum tilled plots strongest. Rotavating generally had an intermediate positon. The effect of one application of gramoxone is shown in Table 5. Although after weeding there was a difference in weedgrowth, at harvest time, however, mostly no differences were noticed.

Table 5. Average area covered by weeds (%) 1= before weeding and 2 = 12 days after weeding.

rotavating		ploughing		minimum tillage	
1	2	1	2	1	2
75	16	69	17	79	29

The big problem of permanent culture of dry crops is the maintainance of soil fertility. As the adsorption capacity is mainly determined by the organic matter content (Nye and Greenland) changes with this respect during the period under investigation had to be regarded. Also changes in soil properties should be considered. It seems that organic matter content remains constant. The same can be said of measured soil physical properties be it that there are clear fluctuations.Fig. 1-4.

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Staff member of the Agricultural University,Wageningen, the Netherlands, Department of Agricultural Engineering.

Fig. 1.
organic
matter
content
% w/w

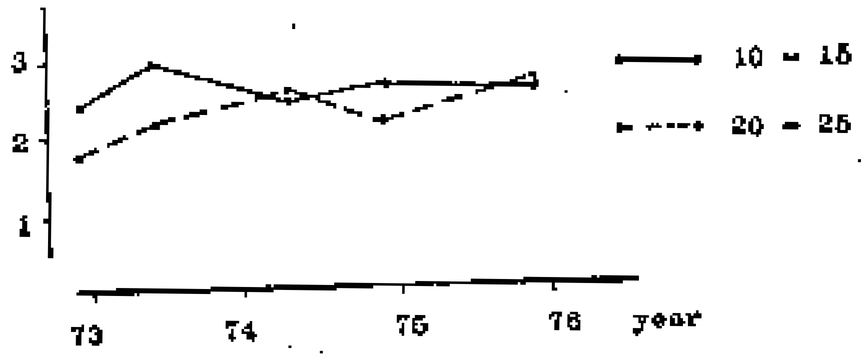


Fig. 2.
pore
space
% v/v

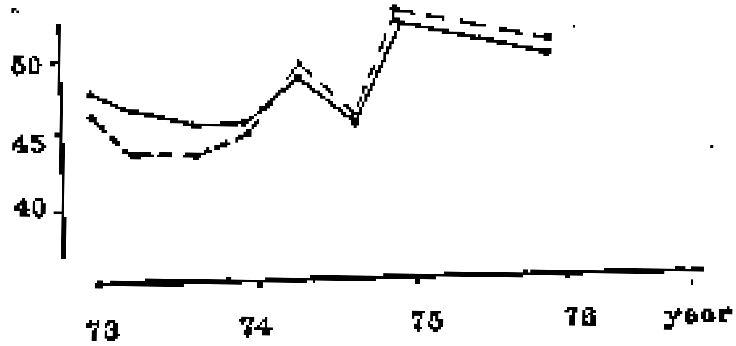


Fig. 3.
aircontent
at pF2
% v/v

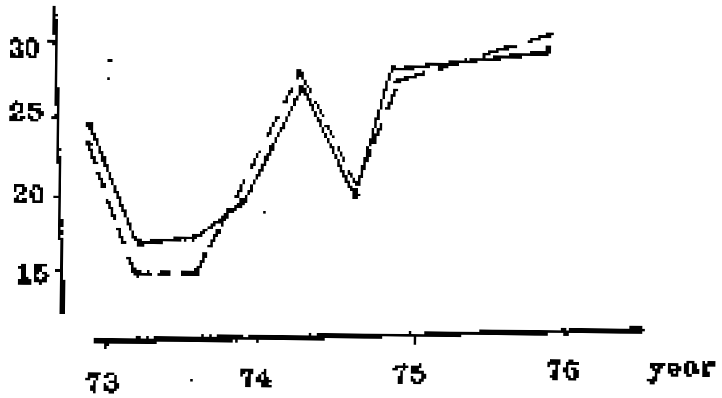
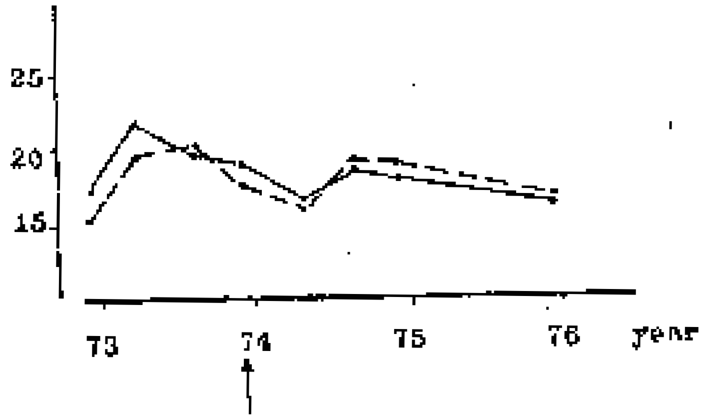


Fig. 4.
water
content
at pF2
% v/v



At this moment trial started in his definite form.

N.B. The curves of the different tillage systems follow closely the average curves shown.

The 7th Conference of the International Soil Tillage Research Organization, Sweden, 1976

TILLAGE PROGRAMMES FOR CEREALS IN SOUTH AUSTRALIA

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ABSTRACT

In South Australia, cereals are sown in late autumn (May-June) while the soil is still wetting up, and mature in early summer(November-December). Water is often limiting during grain filling so an important requirement of tillage programmes is to conserve extra water in the soil. Other limitations in the environment and other requirements of tillage programmes are discussed. The findings of research into tillage practices are discussed in the context of the limitations and requirements.

Introduction

Tillage is an essential part of the mixed crop and livestock system of agriculture in South Australia. Farmers are continually looking for ways of reducing tillage costs and are interested in the effect on yield of alternative techniques such as herbicide sprays and minimum tillage. They are also interested in using bigger machines to give more output per man, because the cost of employing farm labour is high.

In considering tillage programmes for a region it is necessary to first consider the special features and limitations of the environment and to define the requirements of the tillage programmes.

Limitations in our Environment

In South Australia, the main influences on tillage programmes are:

1. Cereals (wheat or barley) are sown in large fields (from 30 to 100 ha) and these often contain different soil types - sands, loams or clays.

2. The soils are generally shallow with a topsoil of less than 15cm; subsoil stone is often present.

3. Soil fertility is only moderate, with the top 7.5cm of the best soils having a total nitrogen content of 0.14 to 0.18 percent.

4. Some of the soils, particularly sands and sandy loams, are liable to either wind or water erosion.

5. Cereals are sown in late autumn (May-June) after sufficient rain has been received to allow completion of seedbed preparation. The onset of early autumn rains following a five month summer drought is unreliable and consequently there is uncertainty as to when sowing can begin.

6. Rainfall in the growing season is below optimum (usually less than 400mm) and there is a high probability of drought.

7. Soils continue to wet up from sowing to the end of the winter rains (August). In spring, rainfall diminishes and air temperature rises so that water stress is common from anthesis onwards. Crops mature in early summer (November-December).

8. Cereals are grown in a rotation in which years of crop alternate with one or more years of annual legume pasture (commonly *Medicago* spp.). Sheep and cattle graze the pastures and the stubble for 3 to 4 months after harvest. Hence, tillage programmes need to be considered in relation to the whole rotation.

9. Farm labour supply is diminishing and is costly when available.

Requirements of Tillage Programmes

It is within this pattern of interacting variables that our tillage programmes must prove effective. Tillage should aim to favour those factors that promote yield and discourage those that depress yield. The main ones in promoting yield are a better water supply, a better nitrogen supply and early sowing. Those that depress yield are poor structure, erosion damage and the presence of weeds, disease and pests. The tillage programme must culminate in the production of a seedbed suitable for cereal grains.

Research Investigations

Research has elucidated some of the factors that help in making decisions on tillage programmes.

1. Length of fallow

The term "fallow" applies when the soil is first broken up in early spring (September) and kept weed-free over summer by cultivation, in preparation for sowing in late autumn. Early experiments showed that this practice benefited wheat crops and yield increases were attributed to a better seedbed, weed control and to increases in soil water storage and soil nitrate nitrogen. These findings encouraged the use of fallow on all soils. However fallow, together with narrow rotations without productive pasture, led to widespread erosion and by 1940 yields were declining in many of the cereal districts (Cornish 1949).

After 1945 the increased use of legume pastures improved soil fertility and many farmers doubted that fallow was needed to give high yields. To test this, French (1966) compared fallow and "short fallow" (in which the soil is first broken up after rain at the end of summer) at five sites in South Australia over five seasons (1957-1961).

Fallow increased wheat yield by 355 kg ha^{-1}, or 34%, over that from short fallow. This increase was obtained at the cost of two additional cultivations and seven months loss of grazing. The individual responses, which varied from -200 to 875 kg ha^{-1}, were related to variations in the additional water and nitrate nitrogen accumulated in the fallow.

Overall, 59% of the yield response to fallow could be ascribed to variation in additional water at sowing. The additional nitrate present in fallow did not increase yields in dry years but in years with favourable growing seasons, the additional nitrate accounted for 33% of the yield response.

From his work, French (1966) prepared a fallow guide to indicate areas in South Australia where fallow should be adopted for wheat. This is shown in table 1. Later studies (Schultz 1971, Schultz 1972, Grierson 1975) have confirmed this fallow guide.

Table 1

Fallow Guide

Previous legume history	Implication	Action required
Poor growth	Likely shortage of nitrogen	1. Fallow* or 2. Add nitrogen fertilizer
Good growth	Likely shortage of moisture	Fallow* only if: 1. Soil is fine textured with more than 20% clay in subsoil (15-30cm). 2. July-August rains in previous winter exceed 100mm. 3. Annual rainfall is less than 460mm.

*Begin fallowing before pastures flower.

The tillage requirements of barley are less demanding than those of wheat. Barley crops are usually grown on short fallow, often following a wheat crop the previous year, because the additional nitrogen in fallow has a deleterious effect on grain malting quality.

2. Type of implement

A variety of implements are used in tillage programmes. From 1957 to 1960 French (unpublished data) compared the yields of wheat from seedbeds prepared with various tillage implements and programmes. The implements used were: (a) mouldboard plough, (b) chisel plough, (c) rigid tyne cultivator, (d) duckfoot cultivator, (e) tandem disc harrows. There was very little effect of implement on yield in an annual tillage programme.

3. Soil surface treatments

In experiments in 1966/67 and 1967/68, Schultz (1972) applied a range of surface treatments to a typical wheat growing soil. The treatments, which were begun in early spring of the year before cropping, were fallow, short fallow, chemical fallow and fallow separately modified by the addition of gypsum, straw or hexadecanol.

The water storage efficiency under each treatment was calculated by expressing the increase in soil water between fallowing (September) and sowing (June) as a percentage of the rainfall during that time. These results, together with the nitrate nitrogen at sowing for each treatment and the subsequent grain yields, are given in table 2.

The water storage efficiencies were higher in the wetter season (1967/68) than in the drier season (1966/67) and in each instance, fallow + straw was the most efficient and short fallow the least efficient. Within each year, grain yields increased with water storage efficiency, emphasizing the need for tillage programmes in our environment to conserve soil water. The nitrate nitrogen contents indicate that mineralization of organic matter was more effective under those treatments which retained most moisture.

4. Minimum tillage

A minimum tillage technique known as "sprayseed" has been used in southern Australia in recent years. The area to be sown is grazed heavily and bipyridyl herbicides are used to kill plant growth a few days before seed is sown directly into uncultivated soil. Benefits claimed from using this technique are additional grazing at a time when pasture availability is normally low, reduced cost of seedbed preparation and maintenance of better soil structure.

<u>Table 2</u>

Water storage efficiency, nitrate-N at sowing and grain yield of wheat for six surface treatments in 1966/67 and 1967/68.

Treatment	1966/67			1967/68		
	Water storage effic-iency %	Nitrate-N at sowing kg ha^{-1} 60cm	Grain yield kg ha^{-1}	Water storage effic-iency %	Nitrate-N at sowing kg ha^{-1} 60cm	Grain yield kg ha^{-1}
Fallow	6	212	387	25	61	2340
Short fallow	-13	152	155	18	47	2000
Chemical fallow	6	198	215	31	59	2370
Fallow + gypsum	10	233	438	31	87	2430
Fallow + straw	11	334	747	34	81	2810
Fallow + hexadecanol	9	278	434	31	64	2470
LSD ($P = 0.05$)	-	119	147	-	n.s.	420
Annual rainfall (mm)	1967 - 278 mm			1968 - 689 mm		

Grierson (1976) compared the technique with fallow and short fallow prepared and sown with tyned (T) and rotary (R) implements. The treatments were applied on the same site in 1974 and 1975 as well as on a new adjacent site in 1975. The wheat grain yields obtained in these experiments are shown in table 3.

In 1974, fallow and short fallow (T) gave similar yields because of the very wet growing season. Short fallow (R) yielded poorly because of weeds and the sprayseed treatments suffered from haydie (Gaeumannomyces graminis). In 1975, on the 1974 site, several treatments were affected by haydie and on the new site, the sprayseed treatments were affected by cereal curculio (Desiantha caudata). In all three experiments, fallow did not suffer from weeds or disease and it yielded more than any other treatment. This confirms numerous other observations that a period of fallow in a rotation reduces the incidence of weeds and disease.

Table 3

Grain yields obtained from five different tillage programmes for wheat in 1974 and 1975.

Treatment	Grain yield t ha^{-1}		
	1974	1975 (1974 site)	1975 (new site)
Fallow	3.09	3.24[+]	3.80
Short fallow (R)*	1.72[x]	2.18[o]	3.52
Short fallow (T)*	3.01	3.08	3.32
Sprayseed (R)	1.53[o]	2.97	2.31[§]
Sprayseed (T)	1.95[o]	2.27[o]	2.29[§]

*(R) = rotary implement for tillage and sowing
(T) = tyned " " " " "

+ Short fallow (T) on previous fallow plots
x Affected by weeds
o Affected by haydie
§ Affected by cereal curculio

5. Erosion damage

Excessive cultivation can lead to wind erosion on sandy soils and water erosion on loamy soils. This risk has been lessened by reducing the number of tillage operations (in many instances from more than eight to four or five) and by the construction of contour banks. The erosion risk on some hard-setting soils can be further reduced by the addition of gypsum to improve the soil's physical properties. There is little interest in stubble mulching as a means of reducing erosion risk.

Stubbles are normally grazed by sheep over summer; in autumn, pasture regenerates or the remaining stubble is burned or worked in, in preparation for a second crop.

6. Time of sowing

Highest wheat yields are normally obtained by sowing before the second week in June. Yields decrease by 20-40 kg ha^{-1} for each day's delay in sowing after mid-June, because anthesis occurs later in spring as water stress develops. Hence, farmers are often prepared to sow on time, even when weather conditions have not allowed preparation of a normal seedbed.

7. Depth of tillage

Experience has shown that there is no advantage in tilling the soil deeper than 7.5cm. Schultz (1975) found that the deep placement of superphosphate (15cm depth) was no more effective than the normal practice of placing superphosphate with the seed at 5cm depth. In many situations in South Australia, deeper tillage would bring stones or clay to the surface.

Conclusions

The condition of the seedbed has usually been regarded as very important for obtaining high yields. However, except for gross defects in the seedbed (e.g. surface crusting or erosion) good results can be obtained in South Australia from seedbeds produced by a variety of tillage programmes. Yields are not sufficiently sensitive to seedbed condition to warrant much modification of the methods used. The main factor encouraging our farmers to change their practices is cost. Two approaches are being taken:

1. The use of bigger machines to prepare and sow land (fallow or short fallow) without the need for additional labour. Farmers aim to cover big areas and are not interested in special techniques to obtain maximum yields on small areas.

2. Reduced-tillage techniques, provided that any loss in yield due to weeds, diseases, pests, lack of soil water or lack of soil nitrogen does not absorb the saving in cost.

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Seed Zone Soil Water Conditions with Reduced Tillage in the Semiarid Central Great Plains 1/

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ABSTRACT

Soil water changes measured by 1-cm increments to the 15-cm depth in all-tillage, reduced-tillage, and no-tillage fallow treatments 1, 12, 19, and 34 days after a 1.35-cm rain are presented and discussed. Soil in the all-tillage treatment dried faster and to a deeper depth than the other two treatments. The no-tillage treatment dried the slowest and to the shallowest depth. Sufficient water to germinate and support initial growth was found at the 14-, 12-, and 7-cm depth for the all-, reduced-, and no-tillage treatments, respectively.

Winter wheat (Triticum aestivum L.) is a well-adapted and extensively planted crop on dryland in the semiarid Central Great Plains. Stable economical wheat production in this area depends on stored soil water, because precipitation amounts and frequencies vary widely. A winter wheat-fallow rotation is commonly practiced to ensure sufficient water storage (5, 6). During the 14-month fallow period, all vegetative growth is generally controlled by tillage.

The development of new and more reliable herbicides since the mid-1960's has generated considerable interest in replacing some or all of the fallow tillage operations necessary for weed control with herbicides (reduced- and no-tillage fallow, respectively). Reduced- and no-tillage fallow systems have significantly increased total fallow period soil water storage (4, 7, 8). Extended dry periods just before seeding the winter wheat crop are common in the semiarid Central Great Plains. Therefore, of major importance is the influence of fallow cultural system on soil water content at the planting depth to insure good germination and initial seedling establishment.

METHODS AND MATERIALS

This study was conducted on the U. S. Central Great Plains Research Station near Akron, Colorado, USA. The semiarid climate of the area has a mean annual temperature of 7°C and receives 80% of the average annual 38 cm of rainfall from April through October. The soil of the experimental area is Weld silt loam which is an Aridic Paleustoll. At field capacity the soil holds 0.33 cm of water per cm of soil.

1/ Contribution from Agricultural Research Service, USDA.

Weed control treatments were replicated 3 times in fallow plots 11 m wide by 30 m long and were (a) subsurface mechanical tillage as needed throughout the 14-month fallow period (all-tillage treatment), (b) residual plus contact herbicides applied only at the start of fallow with subsequent mechanical tillage as needed (2 operations) when the residual herbicide no longer satisfactorily controlled weeds (beginning about the middle of the 12th month after initial herbicide application) (reduced-tillage treatment), and (c) residual plus contact herbicides applied at start of fallow with subsequent contact herbicide applications as needed (2 applications) when the residual herbicide no longer satisfactorily controlled weeds (no-tillage treatment). The residual herbicide used was 2, Chloro-4-ethylamino-6-isopropylamino-s-triazine (Atrazine) at 1.12 kg/ha active ingredient (a.i.). The contact herbicide used was 1,1'-Dimethyl-4,4'-bipyridylium ion as dichloride salt (Paraquat CL) at 0.28 kg/ha a.i.

Soil water was determined gravimetrically in 1-cm increments to a 15-cm depth to encompass the normal 7- to 13-cm seeding depth. Four sites were randomly selected in each treatment in each replication at each sampling. Samples were taken the first day after a rainfall of 1.25 cm or greater, then at 3- or 4-day intervals until the next rainfall. The data reported here were collected during a 34-day period following a rainfall of 1.35-cm. No rain fell during these 34 days, and data collection was stopped by wheat seeding. The soil in the all- and reduced-tillage treatments had been tilled to the 10-cm depth 8 days before the rain and remained weed free during the 34 days without additional tillage. Soil water distribution in the 15-cm soil depth 19 days after the rain was comparable to the water distribution one day before the rain.

RESULTS AND DISCUSSION

Days 1, 12, 19, and 34 after the rain were selected to show the initial and major soil water changes between samplings. Omitted samplings fit uniformly between those shown. Between 1 and 12 days after the rain, soil water decreased drastically in the top 3 cm of soil (Fig. 1A, B, C). The decrease was greatest for the all-tillage treatment. Some of the water lost from the top 3 cm of soil undoubtedly was redistributed because soil below the 9-cm depth showed an increase for all treatments. However the largest loss was due to surface evaporation during first-stage drying. Environmental evaporation potential was high during this time and water in this depth was available for flow to the soil surface. Soil water loss between 3 and 9 cm was greater than the increase between 9 and 15 cm for each of treatment. Evidently some water moved into the soil below the 15-cm sampling depth.

Between the 12th and 19th days, the soil dried to a depth of 4 cm in the all-tillage treatment, but to only 3 cm in the reduced- and no-tillage treatments (Fig. 1A, B, C). The all- and reduced-tillage treatments lost some water throughout the 15-cm sampling depth, whereas the no-tillage treatment had no change in water content below the 6-cm depth. Water loss below the 4-cm depth in the all- and reduced-tillage treatments loss decreased because more of the water had to move to the soil surface as vapor.

By the 34th day after the rain, the top 2 cm of soil of all treatments had the same soil water content (Fig. 1A, B, C). Below this depth, however, the treatments differed strikingly. The all-tillage treatment was dry to a depth of 11 cm, which was the depth of the deepest tillage operation performed during the fallow period. The reduced-tillage treatment was dry to 7 cm and the no-tillage treatment was dry to only 4 cm.

The length of time after the rain that the soil water content was 0.14 cm/cm or greater (the water content needed for seed germination and initial growth) in the 15-cm soil depth is presented in Fig. 2. On the 9th day after the rain the water content of the top centimeter of soil in the all- and reduced-tillage treatments dried to a water content of 0.14 cm/cm. With the no-tillage treatment 12 days were required to dry the top centimeter of soil to a water content of 0.14 cm/cm. The rate of drying in the all-tillage treatment was almost linear from the surface to a depth of 13 cm between the 9th and 26th days. With reduced- and no-tillage treatments the increase in depth of drying was slow until the 26th and 30th days, respectively, when a trend toward rapid drying to deeper depths was noted.

The data in Figure 2 clearly show that with the all-tillage treatment, wheat would have had to be seeded at the 7-cm depth during the first 22 days after the rain. However with the no-tillage treatment, it could have been seeded at the 7-cm depth during 34 days after the rain. At the time of seeding on the 34th day after the rain, the 14-, 12-, and 7-cm soil depths contained sufficient water to germinate wheat and support initial growth for the all-, reduced-, and no-tillage treatments, respectively. All treatments were in third-stage drying at this time and all water moved to the soil surface as vapor. The depth of vapor movement would have been 11, 7, and 4 cm for the all-, reduced-, and no-tillage treatments, respectively. Obviously, tilling the soil created conditions that favored drying deeper than where no-tillage was performed.

During the 34 days following the rain, measured water loss from the 15-cm sampling depth was 2.79, 2.34, and 1.85 cm for the all-, reduced-, and no-tillage treatments, respectively. Water loss during the 34 days was 34% less from the no-tillage treatment than from the all-tillage treatment. Water evaporation from a U. S. Weather Bureau Class "A" pan during this 34 day period was 34.99-cm.

Small amounts of residue on the soil surface will effectively decrease evaporation during the first-stage drying (1, 2, 3) but large quantities of residue are required to save significant amounts of soil water for any extended time. At the time this 34-day drying cycle occurred surface residue had been reduced to approximately 1200 kg/ha on the all-tillage treatment, 2200 kg/ha on the reduced-tillage treatment while 3700 kg/ha was present on the no-tillage treatment. Where tillage had been performed the residue was all flat on the soil surface: on the no-tillage treatment, 50% was still standing. Thus, with no-tillage, sufficient residue may have been present, both flat and standing on the soil surface to effectively decrease turbulent transfer of water vapor to the atmosphere, thereby effectively decreasing depth of soil drying for a longer time.

CONCLUSIONS

Following extended periods without rainfall during fallow, the elimination or reduction of tillage will result in a higher soil water content nearer the soil surface than where only tillage is used. With the higher soil water content nearer the soil surface, the depth at which seeding must be performed to insure good germination and initial growth can be reduced.

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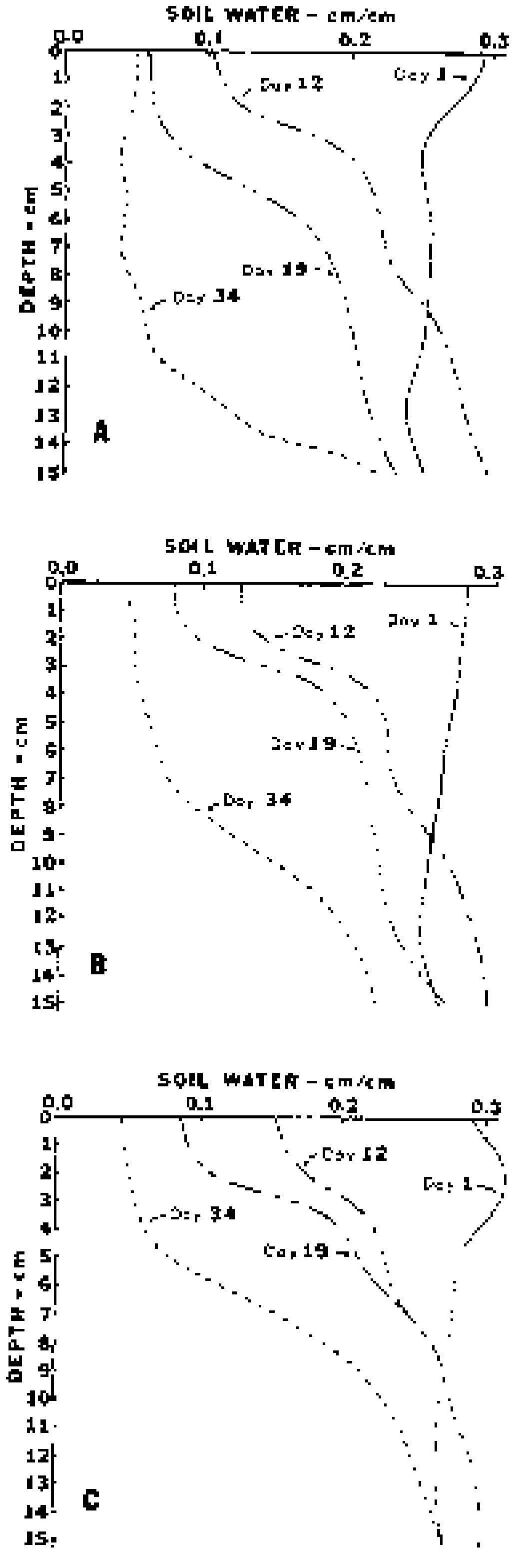

FIGURE 1. Soil water content in top 15 cm of soil on days 1, 12, 19, and 34 after a 1.35-cm rain for all-tillage (A), reduced-tillage (B), and no-tillage (C) fallow treatments.

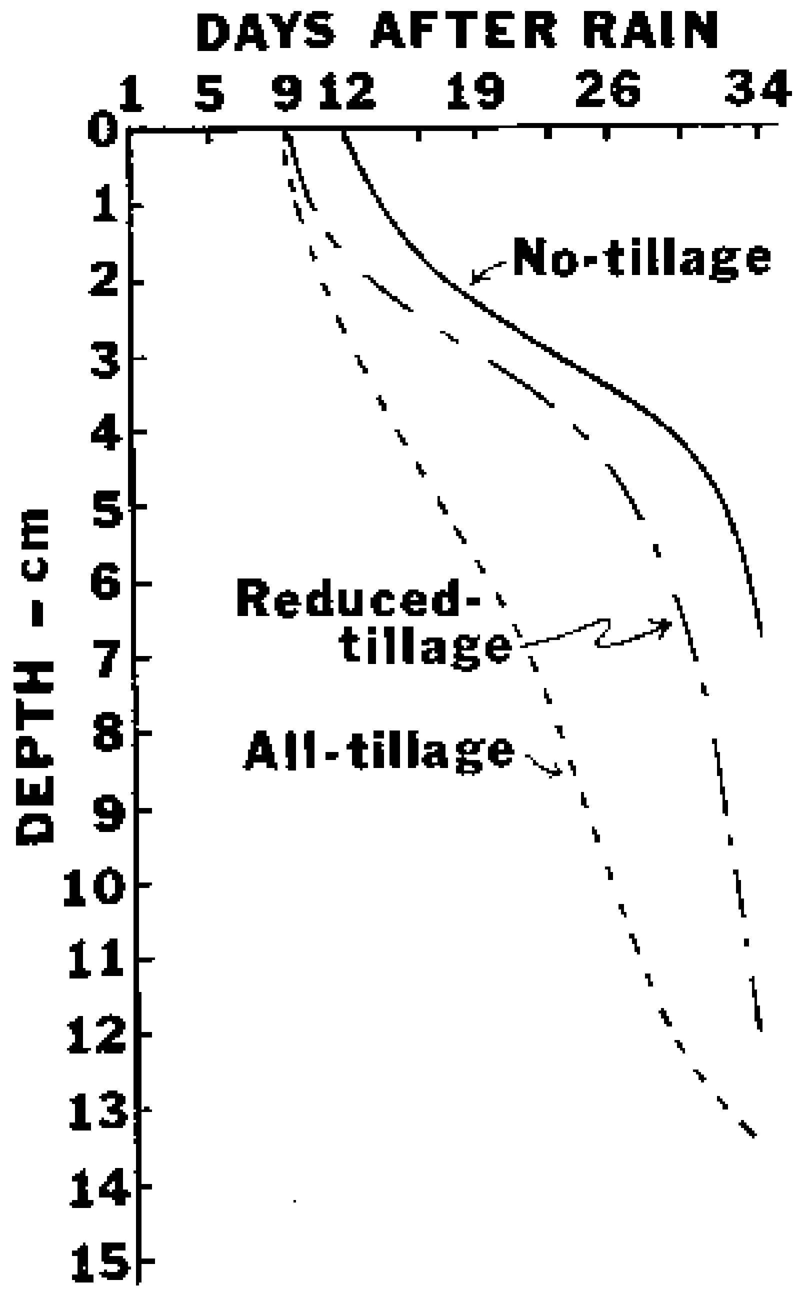

FIGURE 2. Days after rain when soil water content of 0.14 cm/cm available for seed germination and initial growth in the 15-cm soil depth for all-, reduced-, and no-tillage fallow treatment.

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EFFECT OF VARIOUS IMPLEMENTS FOR LAND BEDDING ON PHYSICAL PROPERTIES OF THE SOIL AND YIELD OF CORN GROW ON CHERNOZEM

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ABSTRACT

In 1972-1975 on chernozem soil type a field experiment with maize was carried out with two ploughing depths (15-20 and 30-35 cm) and 5 methods of pre-planting preparation (discing, one rolling, two rollings, Rau-comby and Fulvi-mulcher).

On the basis of four-year investigations the following conclusions have been reached: the optimum physical soil properties and the best conditions for maize growing could be obtained by using that pre-planting implement for the pre-planting preparation which provides these factors. Rau-comby krümler was the implement which provided the highest number of harvested plants and the highest yield of maize grain per ha in our examinations.

I N T R O D U C T I O N

The physical properties of the soil, primarily its compaction expressed through its volume weight, bear great influence on the soil productivity (Revut, 1971), growth, development and plant yield. Ploughing depths, different implements of preplanting preparation, time and methods of these implements used affect differently on soil physical properties. Hence, those pre-planting implements have to be chosen for pre-planting which accomplishe the highest number of elements for top quality pre-planting preparation.

On basis of the results of Stranak (1966, 1967, 1970) from model experiments a positive reaction of certain cereals was found on a stronger soil compaction especially in planting layer depending on soil type.

The aim of our investigations was to examin the effect of two ploughing depths and various pre-planting implements on the soil compaction and maize yield under field conditions.

CLIMATIC CONDITIONS

1967 was one of the best year for maize growing with respect to the temperature and moisture. During the vegetation period, from IV to IX month, it was 463 mm rainfall with plenty of winter moisture supply (90 mm) and abundant rainfall in June (140 mm) and July (169 mm).

1968 was one of the poorest year for maize growing. During the vegetation period it was only 290 mm rainfall which together with winter moisture supply 64 mm amounted to 357 mm, and the potential evapotranspiration to 499 mm. Consequently the moisture dificiency was 142 mm.

1969 was middling for maize production. During the vegetation period there was 332 mm rainfall which amounted to 385 with the winter moisture supply of 53 mm. Potential evapotranspiration was 475 mm. Hence the moisture defficiency was 90 mm. However, this defficiency appeared mostly in time when the moisture maize need was reduced hence the reduce of maize yield was not greatly affected.

In 1970 the soil was supplied with sufficiant moisture during the whole vegetation period. Hence the soil layer of 0-80 cm depth had over 20 moisture weight percentage during intensive growing and tasseling until the middle of July.

The maize yields in experimental period depended on climatic conditions, agrotechnical measures and number of productive plants per area unit.

M E T H O D S

The field experiment was carried out on the chernozem soil type of good physical, chemical and biological properties in wheat-maize rotation.

The following variants were examined: I - Ploughing depths: a) 15-20 cm and b) 30-32 cm; II - Pre-planting preparation: a) discing + harrowing; b) discing + one rolling with 1000 kg weight; c) discing + two rollings with 2000 kg weight; d) Rau-comby; e) Pulvi-mulcher (Kongskilde). Compaction of planting layer was performed before planting. Fertilizing was carried out with 102 kg/ha N, 64 kg P_2O_5 and 52 kg/ha K_2O in standard system.

The planting was performed with sowing machine YU-SKPD-4 (6.V.1967, 24.IV.1968, 28.IV.1969 and 7.V.1970).

During pre-planting preparation the soil moisture of planting layer was near the field water capacity as follows: 1967. 26%, 1968. 19%, 1969. 23%, and 1970. 25% weight percentage. The soil samples were taken with 100 cm^3 metal cylinders per each 10 cm depth in 5 replicants.

The size of experimental-plot was 322 m^2. Single cross hybrid NSSC-70 seed was used for planting.

RESEARCH RESULTS AND DISCUSSION

Data of volume weight per soil layers and maize grain yield per year examined are presented on table 1.The data indicate that the volume weight was increased by the increase depth of ploughing and it was very different with different pre-planting implements.

The optimum soil volume weight on the carbonate soil for maize amounted to 1,2-1,3 gr/cm^3 (Atamanjuk,1971. Ševljagin, 1968, Grinko 1968). The same authors found that the yield was increased by the compaction increase of 0,96-1,2-1,3 gr/cm^3, however the values below and under these factors had a negative affect on the water- air requirement of the soil and the height of yield obtained.

According to our investigations the compaction variant (Rau-combi) by which the highest yield was obtained, was in limits 1,16-1,36 gr/cm^3; however, the other pre-planting implements had lower or higher compaction and as a result in both cases the yield results were lower.

A special low yield was noticed with "two rollings" as there was a high volume weight (from 1,31-1,47), in the layer 0-10 cm which hindered germination and the number of seedlings.

Disc-harrow used as a preplanting implement has not proved adequate as in layer 0-10 cm it left the soil very loose (1,06-1,14 gr/cm^3), which had a bad effect on the yield in 1969.

The data indicate that there were no such regularity under field conditions as in model experiments obtained by Kovačev - 1972, Tretjakov - 1974, Vasiljev - 1965 and Revut - 1962.

Tab. 1 Wolumen weight of soil (g/cm^3) and Yield of Corn grain q/ha (with 14% moisture)

(Ploughind depth - 20 cm)

Depth	Discing				1 rolling				2 rolling				Rau-comby			Pulvi mulcher		
(cm)	'67.	'68.	'69.	'70.	'67.	'68.	'69.	'70.	'67.	'68.	'69.	'70.	'68.	'69.	'70.	'68.	'69.	'70.
0-10 cm	1,10	-	1,09	1,14	1,27	-	1,28	1,28	1,47	-	1,32	1,34	-	1,24	1,25	-	1,21	1,26
10-20 cm	1,23	-	1,19	1,25	1,41	-	1,32	1,40	1,47	-	1,38	1,43	-	1,36	1,36	-	1,39	1,40
Yield (q/ha)	91	-	83	114	85	-	90	109	81	-	73	97	-	95	118	-	93	112

(Ploughing depth - 30 cm)

0-10 cm	1,13	1,06	1,07	1,12	1,31	1,25	1,30	1,35	1,34	1,31	1,32	1,38	1,16	1,28	1,25	1,18	1,30	1,28
10-20 cm	1,23	1,29	1,20	1,23	1,37	1,35	1,32	1,36	1,40	1,37	1,38	1,40	1,32	1,36	1,36	1,40	1,38	1,38
20-30 cm	1,29	1,34	1,25	1,34	1,45	1,37	1,38	1,39	1,45	1,39	1,40	1,41	1,35	1,40	1,40	1,41	1,42	1,40
Yield (q/ha)	90	66	88	112	83	64	86	104	75	69	77	107	75	87	121	72	77	115

Table 2. shows the data of grain yield and number of harvested Maize cob depending on ploughing depth and pre-planting implements.

The data indicate that very different yields were obtained per year depending on the climatic conditions and number of well developed plants and less on the soil compaction.

In 1967, 1968 and 1970 there were no significant differences in yields obtained between ploughing depths. However, there were significant differences between pre-planting implements each year. Thus in 1967 the highest yield with disc-harrow was obtained with 99% probability. In 1968 the highest yield was obtained with Rau-combi whereas discing and one rolling proved significantly poorer performance.

In 1969 the highest yield was obtained with Rau-combi (91 q/ha) and the greatest number of Maize cob harvested (35 500 plants/ha). The lowest yield (75 q/ha) and smallest number of Maize cob harvested (26 300/ha) was obtained with two rollings. That is fully understandable as with that variant in all layers and both depths the soil compaction was the highest ranging from 1,32-1,40 gr/cm^3. Consequently a great number of seeds was left on the soil surface, but even for the seeds planted there were no favorable conditions for germination because of less pore volume and air, unfavorable conditions for germination, shooting, growth and yield delay.

In 1970 the highest yields were obtained because of optimum moisture throughout the whole vegetative period and the greatest number of harvested plants. In this year too the highest yields were obtained (119,7 q/ha) and the greatest number of Maize cob harvested (44,600) by using the pre-planting implement Rau-combi, whereas the lowest yield (102,2 q/ha) and the smallest number of plants (36,800) were obtained with two rollings. The differences were proved by over 99% probability.

C O N C L U S I O N

On the basis of the four year examination on chernozem soil the following conclusion has been reached:

Tab. 2. Effect of ploughing depth, method of pre-planting preparation on Yield of Corn grain (q/ha) and number of Corn cob/ha NSSC-70

Ploughing depth (cm) (A)	Pre-planting implement (B)	1967. q/ha $\bar{X}$ AB	1967. (000) Plants/ha	1968. q/ha $\bar{X}$ AB	1968. (000) Plants/ha	1969. q/ha $\bar{X}$ AB	1969. (000) Plants/ha	1970. q/ha $\bar{X}$ AB	1970. (000) Plants/ha
	T+	91	-	-	-	83	32	114	42
	1 V	85	-	-	-	90	34	109	41
15-20	2 V	81	-	-	-	73	27	97	36
	RC	-	-	-	-	95	37	118	44
	SS	-	-	-	-	91	34	112	43
	$\bar{X}$ A	86	-	-	-	86	33	110	41
	T+	90	-	66	37	88	35	113	43
	1 V	81	-	64	35	86	32	104	39
30-35	2 V	75	-	69	37	77	30	107	37
	RC	-	-	75	38	87	35	121	45
	SS	-	-	72	38	77	30	115	43
	$\bar{X}$ A	83	-	69	37	83	32	112	41
	T+	91	-	-	-	85	33	113	42
	1 V	84	-	-	-	88	33	106	40
$\bar{X}$ B	2 V	78	-	-	-	75	28	102	37
	RC	-	-	-	-	91	36	120	45
	SS	-	-	-	-	84	32	113	43
		5%	1%	5%	1%	5%	1%	5%	1%
L S D	A	4	6	-	-	7	7	5	5
	B	5	7	6	9	11	12	7	8
	AB	8	10	-	-	15	17	10	11

T+ = Disc-harrow
1 V = 1 rolling
2 V = 2 rolling
RC = Rau-combi
SS = Pulvi mulcher

For pre-planting soil preparation for maize those pre-planting implements should be used which provide the optima physical soil properties and offer conditions for optima planting depth, shooting and growth of the greatest number of germinative seeds planted. Rau-combi krimpler was the implement used in our examinations which provided all those elements.

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Evaluation of physical properties of cultivated layers for the comparison of different tillage treatments

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Abstract

The paper outlines a technique, based on the use of large (350 mm diameter) undisturbed soil samples, for determining the important soil physical properties which influence the moisture status and strength of different soil tilths. A photographic method for tilth definition and the determination of clod size distribution within a profile is discussed.

Introduction

In the United Kingdom, significant yield increases may be gained from the timely sowing of most crops. Due, however, to the unfavourable moisture status and strength of the soil, spring sowing frequently takes place after the optimum date. Investigations are proceeding at the National College to determine the effect of different autumn tillage treatments on the workability and trafficability of the soil in the following spring; a wide range of tilths are being considered.

The sooner a cultivated soil approaches a moisture content close to the plastic limit after rain, the earlier seed-bed preparations can begin. The time required for such a change to occur will depend upon the overall drainage status of the profile, the drainage rate in the cultivated layer, the field capacity moisture content and the rate of moisture depletion resulting from evaporation. In many soils, field capacity is usually above the plastic limit and therefore, the management objectives should be aimed at minimising field capacity and maximising the evaporation rate. These aims will also increase soil strength in a given profile. The main physical parameters required to evaluate differences between tillage treatments in this context are soil density, volumetric moisture content, moisture content/suction relationship, profile drying rate, and the soil strength/suction/density relationship. This paper describes a technique which is being used to determine these parameters and it includes both field and laboratory measurements.

Moisture status and soil strength evaluation

The size of sample required to ensure representative sampling is large when very coarse tilths (clod size up to 150 mm diameter) are considered. 'In situ' measuring techniques for moisture content, suction and density should offer advantages, but there are significant calibration problems and difficulties in accurately monitoring the conditions close to the surface. The results obtained from field plots are dependent upon the weather patterns in that particular season. The weather, unfortunately, does not always provide the range of conditions required. To overcome many of these problems and to make optimum use of the available labour, a technique has been developed where 350 mm diameter, 250 mm deep undisturbed samples are collected from the field plots.

Sampling technique

The sampling tube (PVC Class B pipe) fitted with a cutting ring is jacked into the sample area. The reaction being taken by a cross beam held by two ground anchors, fig. 1. The sample is carefully excavated, inverted to remove the cutting ring and a base plate inserted. During inversion the irregular soil surface of the sample is supported and protected with soft packing cloth. Sampling is relatively simple on cultivated plots, but problems can arise in hard, dry compact conditions. On hard plots, a combined hammering and jacking action, together with soil excavation around the cutting ring assists penetration without creating significant soil disturbance. The samples weigh up to 40 kg and a 3 man team can take 15 samples in a 4 - 5 hour period.

Volumetric moisture content and density

The volumetric moisture content and density are determined for increments of soil depth by cutting the soil off in layers and using a thermo-gravimetric technique. By field sampling at the appropriate time interval after rain, the field capacity moisture content and density can be determined. Surface elevation and roughness measurements are made in the field using a relief meter (Kuipers 1957), allowing overall density changes with time to be monitored over a larger area.

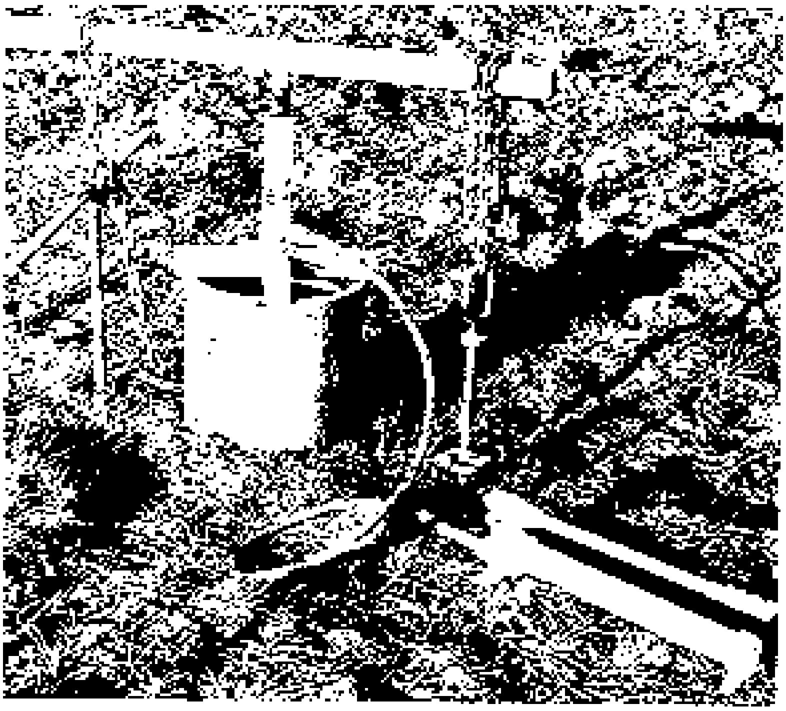

Fig. 1
Sampling
Equipment

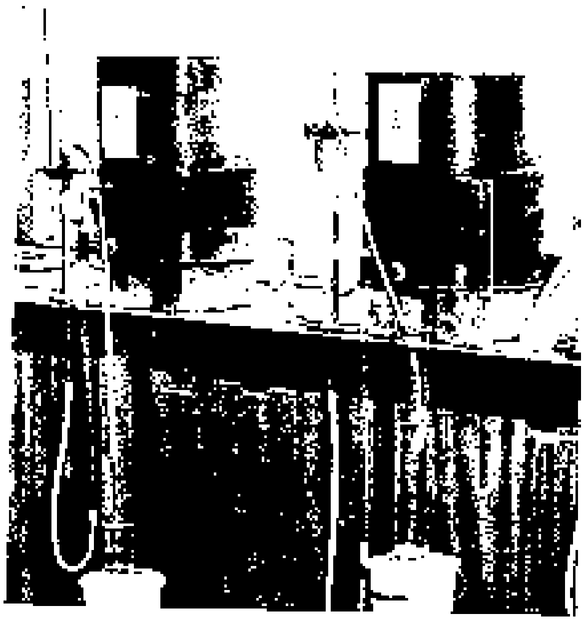

Fig. 2
Large sample
on sand table

Suction/moisture content relationship

A measure of the soil moisture content/suction relationship can be obtained by placing the large samples on a sand table capable of operating up to suctions of 1 m, fig. 2. Using this technique, the sample can be brought to any equilibrium suction between saturation and 1 m (Haarst and Stakman 1965). This simulates the effect of different phreatic water levels in the soil profile, and the total volume of water released over the different suction ranges can be measured. The volume released provides a useful measure of the volume of large readily drained structural pores at different depths in the profile and can be compared with estimates from the density and field capacity data. In addition, the volume extracted gives an immediate assessment of the change in field capacity moisture content which would result from a change in the field water table position. Table 1. illustrates for a silty clay soil.

Moisture suction measured from surface m	Volumetric Moisture Content of top .20 m %		
	Very coarse tilth	Very fine tilth	Undisturbed plot
0.25	37.7	42.2	41.1
0.45	35.4	37.6	39.4
0.65	33.9	35.7	38.4
0.85	33.1	34.1	37.2

Table 1. Equilibrium moisture content of different tilths at different suctions

Poor contact between the sample and the side of the sampling tube has not proved to be a problem on the cultivated profiles. Care, however, is needed with the high density undisturbed samples to ensure there are no large volume gaps at the sides.

Moisture/strength relationship

Soil strength is assessed indirectly in the field using tractor wheel sinkage tests. The strength of the uncultivated and finer tilths can be assessed at a range of moisture suctions using the large samples on the sand table. Problems arise with the coarse tilths, where the size of the clod either approaches or is greater than the size of the measuring device, e.g. shear vane, penetrometer or bevameter. Although a plate/sinkage test will give some estimate with a coarse tilth sample, field measurements are preferred.

Profile drying characteristic

Work is proceeding on the measurement of water diffusivity of the profiles at different volumetric moisture contents, to estimate drying rates after field capacity has been reached. The sand tables are used to bring the large samples to the required equilibrium moisture suction before the test.

Thermal properties

The thermal properties of the tilths are measured at the different equilibrium moisture suction values during the drawdown process on the sand tables. Three sets of five thermocouples are inserted through the sides of the well lagged sample tube at the appropriate depths and the thermal diffusivity estimated using the method of van Wijk. (Wijk 1963).

Tilth definition

One of the most useful ways of defining a tilth for scientific purposes is to define it in terms of its porosity and pore size distribution and its physical properties. However, this definition is of little value to the farmer who has to produce a specific tilth in the field. Tilths are frequently defined in terms of clod size distribution, the distribution being determined using sieving techniques. Sieving tends to be time consuming and difficult, particularly under wet conditions and the results are sometimes very variable. To overcome some of these problems a photographic technique is being used where a grid of standard dimensions is laid on to the soil surface and a photograph taken from a standard height, with the line of sight perpendicular to the surface and the grid, fig. 3. The photograph can be analysed to determine the clod size distribution (Nellist 1961), or compared with a series of standard photographs of known clod size distribution and ranked according to the coarseness of the tilth. The use of stereo pairs of photographs has helped in the analysis of clod size distributions and in micro-relief studies on the soil surface, (Spruijt 1974).

This photographic technique is directly applicable to the soil surface, but can also be used for the assessment of the vertical distribution of clods (Spruijt 1974). For the vertical distribution, a sloping profile, approximately 25° to the horizontal, is carefully prepared by hand with minimum disturbance of the clods, to show a representative distribution of clods with depth. The sloping profile is then photographed with the line of sight perpendicular to the surface.

Table 2 allows the comparison of the photographic method with a sieving method for assessing changes in clod size distribution with depth. The photographic technique for clod size determination is most satisfactory for tilths containing discrete clods, such as those freshly cultivated. The method becomes increasingly difficult to use as the clods weather and settle.

Clod fraction	Sieving 1	Sieving 2	Sieving average %	Photo Analysis 1	Photo Analysis 2	Photo Analysis average %
$>1\frac{1}{2}$ in	20.1	24.5	22.3	22.1	20.5	21.3
$1\frac{1}{2} - \frac{3}{4}$ in	19.9	18.7	19.3	17.1	15.0	16.1
$\frac{3}{4} - {}^{3}/_{8}$ in	15.8	18.8	17.3	14.1	15.2	14.7
$<{}^{3}/_{8}$ in	44.2	38.0	41.1	46.7	49.3	47.9

Table 2 Clod size distribution in vertical profile

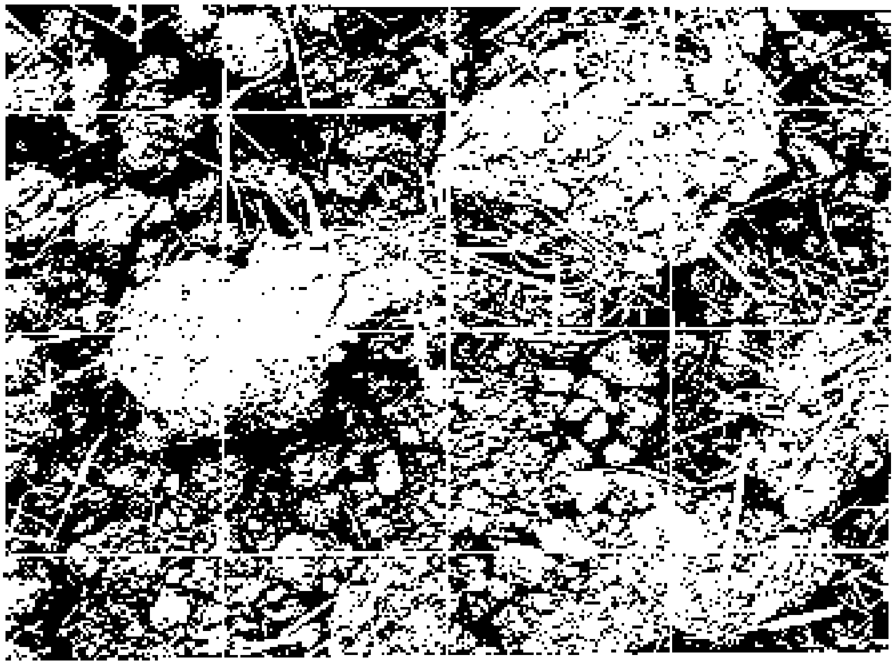

Fig. 3 Soil surface showing grid

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AN INVESTIGATION INTO THE EFFECT OF SPEED ON THE DRAUGHT REQUIREMENTS OF A CHISEL TINE

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ABSTRACT

Measurements of the draught force acting on a simple tine have been made in a laboratory soil bin and in the field over a range of speed (5 mm s^{-1} – 6 m s^{-1}) and soil moisture content (8–33%). Existing theories in soil mechanics adequately predict the draught force at very low speed but further models need to be developed to explain both the change in draught with speed and the dependence of the draught/speed characteristic on soil properties.

INTRODUCTION

The design of cultivation implements in a systematic manner is dependent on adequate knowledge of the behaviour of implements in various soils and operating conditions. The mechanics of plane tools of simple shape has been developed for very low forward speed. The trend in recent years has been to increase cultivation speeds. This has highlighted the need for a soil mechanics to cope with the effect of speed and also the shortage of experimental observation of speed effects on the performance of tillage tools.

It has been accepted for many years that the draught force on mouldboard ploughs increases in proportion to the square of the forward speed due to acceleration of the failed soil mass. Hence Goryachkin(1) and Soehne(2) proposed a draught/speed equation of the form:

$$D = D_o + av^2 \qquad (1)$$

where D is the draught force, D_o 'draught force at zero speed', v forward speed, a constant.

The component D_o in the case of chisel tines and wide cutting blades is the force that the tine must exert on the soil to just produce failure planes through the soil mass. It may be compared with the parallel situation in civil engineering soil mechanics of retaining walls and of the bearing capacity of footings. Reece(3) has used this comparison to propose an additive equation to calculate D_o for wide cutting blades involving two-dimensional soil failure based on Terzaghi's equation for bearing capacity(4). This assumes failure surfaces of a log spiral shape and is composed of terms due to soil cohesion, density, surcharge and soil to implement adhesion. A practical form of this equation has been proposed by Hettiaratchi, Witney and Reece(5) as:

$$D_o = \left[(\gamma z^2 N_\gamma + czN_c + c_a zN_a + qzN_q) \sin(\alpha + \delta) + c_a z \cot\alpha \right] b \qquad (2)$$

where γ is soil weight, z depth of cut, c cohesion, c_a adhesion, q surcharge pressure, α rake angle of blade, δ angle of soil/metal friction, b width of blade. The N factors are numerical quantities dependent on $\emptyset$, the angle of internal friction, α and δ. The values of N for a range of $\emptyset$, α and δ were computed by Hettiaratchi et al and are reported in their paper.

Narrow tines cause soil failure planes to the front and to the sides of the tine (see Payne (6)) and the forces due to the side failures are comparable with those to the front. Reece's simplified two-dimensional analysis cannot therefore be applied but Hettiaratchi and Reece(7) have proposed a semi-empirical solution as an extension to the two-dimensional analysis.

Comparison of measured draught force/speed characteristics with equation 1 have clearly demonstrated that it is deficient (e.g. Wismer and Luth(8)). In recent years, the increase of draught force with speed has been attributed to change of soil shear strength with strain rate(9), speed dependence of soil failure pattern(10), visco-plastic effects(11) and rate of propagation of stress waves through soil(12).

Acceleration forces are clearly significant in the case of mouldboard ploughs and bulldozer blades which move a comparatively large mass of soil. However, their contribution to the increase of draught with speed for tined implements is questionable because of the small amount of soil movement. Wismer and Luth(8) have shown that draught increases with the square of speed ($D\alpha v^2$) for a plane blade in air dry sand but that in a saturated clay draught is proportional to v^n where n is less than 1. Although inertial forces still contribute to the increase of draught, their curve for clay implies that the dominant component is due to the change of shear strength with strain rate.

The effects observed by Wismer and Luth may have been due to the different mechanical properties caused by the different textural composition of clay and sand but, equally, they may have been due to the different moisture levels in the two soils; air dry sand and saturated clay. Indeed, as rate effects are, in part, related to movement of water through the soil matrix, it is suggested that moisture level is the pertinent factor. If that is true, then it would be expected that the shape of the draught/speed characteristic in the experiments that are reported here would change with soil moisture content.

The shape of the draught/speed characteristic is important as it affects the increased draught power requirement at higher speeds. For a given implement, tractor and field conditions, the shape of the characteristic will determine the optimum speed for cultivation. Pertinent to this is an interesting phenomenon observed by Russian workers(e.g. 13) and reviewed by Hendrick and Gill(14) that at sufficiently high speeds the draught force decreases with speed. The effect occurs at speeds above the rate of propagation of stress waves through soil (of the order of 10–12 m s^{-1} in unsaturated agricultural soils).

The aims of the present investigation were to measure the draught force/speed characteristics over a range of soil and implement variables and compare the measured draught forces at very low speeds with those predicted by equation 2. The nature and extent of soil disruption over a range of speeds was also investigated. Experiments were carried out both in a laboratory soil bin and in the field.

LABORATORY EXPERIMENTS

A soil bin, 3 m long, which has been described previously(15), was used for the laboratory experiments. The tine support frame was suspended by six dynamometer linkages from an overhead carriage which was propelled along overhead rails by a D.C. controlled electric motor via a cable winch. The carriage could be accelerated to any desired speed in the range 0.005-3.5 ms^{-1} before the tine entered the soil bin. The signals from the six transducers and a signal proportional to carriage speed were recorded on magnetic tape. The taped signals were later analysed by a digital computer to give three perpendicular forces and three couples to define the force system acting on the tine. The forces quoted later in the paper are the mean values from the computer analysis unless otherwise stated.

A high speed cine camera was mounted on the carriage to photograph the failure patterns in front of the tine at upto one frame per mm of forward movement.

Simple flat plate chisel tines of 40 mm width were used. The rake angles (to the forward horizontal) of the tines were 45°, 67° and 90°. As these narrow tines caused three-dimensional soil failure and equation 2 applies to two-dimensional failure, a wider blade (465 mm wide) was used for a few experiments.

A sandy clay loam soil was used in the bin; its properties are given in Table 1. It was prepared in the bin to the required density by a processing unit fitted to the overhead carriage, consisting of rotary cultivator blades and vibrating compaction rollers. The rollers were loaded onto the soil surface by a hydraulic ram so that the compaction pressure could be maintained constant.

FIELD EXPERIMENTS

The same tines were again supported in a frame suspended by six dynamometer linkages from a mobile rig which was towed by a tractor. The working depth was controlled by a depth wheel which also drove a tacho-generator to give a speed signal. The instrumentation was carried in a vehicle following the rig and joined to the rig transducers by a trailing cable.

Measurements were made in two experimental plots under various conditions. The soil in plot 1 was the same as that used in the soil bin so that direct comparisons could be made between field and soil bin results. The plot was divided into three areas so that measurements could be made under three different conditions, viz. a) fallow, average moisture content 18.6% d.b., b) stubble, average moisture content 9.3% and c) fallow, average moisture content 16.4%. The areas used for conditions a and c had remained fallow for five years and were prepared by rotavating several months prior to the experiments. As the ground did not settle sufficiently, it was compacted by running a track-laying tractor over it two weeks before the experiments. The soil in plot 2 had a higher sand content than plot 1 and measurements were made under two conditions, viz. a) fallow, average moisture content 11.8% d.b. and b) stubble, average moisture content 11.1%. The properties of the soils are shown in Table 1 and the penetration resistance of a 30° cone is shown in Table 2.

DRAUGHT FORCE AT VERY LOW SPEED

In order to verify the use of equation 2 for two-dimensional soil failure, the wide blade was pulled through the soil bin at speed of 5 mms^{-1} so that soil failures very similar to static failures would be induced. The blade was set at rake angles of 45°, 67° and 90° and the working depth was 50 mm. The measured draught force is compared with the value calculated from equation 2 in Table 3. The draught oscillated as the blade moved forward, the maximum value in each cycle being caused by the formation of new shear planes in the soil.

TABLE 3. Draught force on wide blade (Newtons)

rake angle	45°	67°	90°
measured mean	1150	1590	1960
max.	1490	2150	3020
calculated	1480	2600	3420

TABLE 4. Draught force on narrow tines (Newtons)

rake angle	45°	67°	90°
measured	1630	1240	1530
narrow tine model	6750	10620	12170
wide tine model	480	780	1450

The maximum measured draught agreed with the calculated value at a 45° rake angle but diverged as the angle was increased.

The experiments were then repeated using narrow (40 mm wide) tines to compare the predictions of equation 2 and of Hettiaratchi and Reece's(7) model for narrow cutting blades. The working depth was 150 mm; the draught forces are listed in Table 4. The draught force signal did not oscillate and the mean value is given in the table.

The failure caused by the narrow tines was three-dimensional, of the type described by Payne(8). However, the values calculated from the three-dimensional model were an order of magnitude greater than the measured values. The high values were found to be due primarily to the high value of cohesion (30.2 kPa) measured in these particular experiments. The model was clearly defective for application to these experimental conditions. Values were then calculated from equation 2 (although this model does not include the full failure zone). The forces were, indeed, lower than the measured values but were of the right order. It was decided, therefore, to use equation 2 as the basis for D_S in equation 5.

THE EFFECT OF SPEED ON DRAUGHT IN THE SOIL BIN

A series of experiments were undertaken in the soil bin to determine the draught/speed characteristic for narrow tines at rake angles of 45°, 67° and 90° at 150 mm working depth. The draught forces are plotted in Figs. 1, 2 and 3. Regression analysis was applied to the results and the best fitting curve was found to be an exponential of the form:-

$$D = A - Be^{-CV} \tag{3}$$

where A, B and C are constants.

The full curve was fitted to the points with no restriction. The dashed curve was forced through the zero-speed force, D_0, calculated from equation 2 (using mean values of soil properties from all experiments). The chain curve shows how the soil inertial forces might be expected to increase the draught with speed. The inertial force was calculated on the assumption that two-dimensional failure blocks were created periodically in front of the tine at an angle of $(45-\frac{\phi}{2})$ to the horizontal. The curve was forced through the calculated value of D_0.

At each rake angle, the draught force increased with speed, the highest rate of increase occurring with a 45° tine. The rate of increase decreased with increasing speed, in contrast to the results of Stevens and Luth(8) for an air-dry sand but in agreement with their results for a saturated clay. The small difference between the free fitted curve and that forced through D_0 substantiated the use of the two-dimensional failure model.

The vertical forces acting on the tine are shown in Fig.4. They increased with speed in a similar manner to the draught forces. The analysis on which equation 2 was based was used to calculate the vertical forces at zero speed. They are marked on Fig. 4.

FIELD EXPERIMENTS IN PLOT 1

The soil in plot 1 was the same as that used in the soil bin. For condition A the moisture content was slightly higher (18.6%) than in the soil bin (18.0%).

The forces exerted on tines of rake angles 45°, 67° and 90° (150 mm working depth) were recorded over a speed range of 0.25 - 2.0 ms^{-1} for two replicates. Curves of the form of equation 3 were found to fit the results for the 45° and 67° tines very well. The results for the 90° tine were too scattered to fit a curve. As the curves for the 45° and 67° tines did not differ significantly from each other, a common curve was fitted through all results (Fig.5.).

The vertical forces are plotted in Fig.6. Both draught and vertical forces were very similar in form to the results from the soil bin. However, due to soil in field being more compact than the soil in the bin, the draught increased at a slightly higher rate and the forces were higher (see Table 2).

Similar draught force measurements were made when the soil moisture content was 15.8% (condition C). A greater speed range of 0.7-4.5 ms^{-1} was covered. The draught forces for 90° and 45° tines are plotted in Fig. 7. The scatter was such that only straight lines could be fitted. The scatter was again greater for the 90° tine where the regression line was only significant at the 10% level. The draught/speed characteristic was very different to that for soil 1A with the rate of increase of draught being smaller and no evidence of the rate of draught increase decreasing with speed.

Due to the very dry summer in 1975, it was possible to conduct further measurements on plot 1 at a moisture content of 5.3% (condition B). The soil would be described as 'air-dry' at this level. Due to the very hard soil conditions, the measurements had to be made at 75 mm depth. The draught/speed characteristics for 67° and 90° tines are shown in Fig. 8. A straight line was fitted to the 67° results but there was too much scatter in the 90° results to fit a line. The increase in draught with speed for the 67° tine was much smaller than for the previous results and no increase at all was evident with the 90° tine.

FIELD EXPERIMENTS IN PLOT 2

Similar measurements were made in plot 2 using 45°, 67° and 90° tines at a depth of 150 mm. The draught forces are plotted in Fig. 9 with the results for conditions A and B plotted on the same graph. There appeared to be no consistent difference between the results for the fallow and stubble conditions and it was concluded that the stubble had no significant effect on the results. Straight regression lines were fitted to the results for the 67° and 90° tines. The results for the 45° tine showed a distinct curvature and a parabolic curve was fitted.

THE EXTENT OF SOIL FAILURE

In order to quantify the amount of soil disturbance by the tine, the shape of each furrow was measured by a profilemeter. The measured furrow shapes for a large number of soil bin and field experiments were examined and it was found that they approximated very closely to normal distribution curves. Normal curves were, therefore, fitted to each set of data and the furrow cross-sectional areas were calculated from the curves. The effect of speed on furrow shape could then be examined. The degree of scatter in the results was such that straight lines could be fitted in a few cases only. Examples for a tine of 90° rake angle are shown in Fig. 10. In the cases where lines could be fitted the area increased by 30% or less in the speed range 0-5 ms^{-1}.

CONCLUSION

The Hettiaratchi, Witney and Reece(5) two-dimensional model of soil failure has been shown to predict the draught force on a narrow tine at very low speed with reasonable accuracy and can therefore be used as a basis for developing a speed dependant model of soil failure. The experimental results have shown that the change in draught force with speed is very dependent on soil type and condition.

The change in draught with speed is attributable to: a) inertial forces, b) change in volume of failed soil and c) shear rate dependence of cohesion, adhesion and angle of friction. In the case of the dry soil (1B), even the small increase of draught at the 67° tine cannot be wholly explained as due to inertial forces (see Fig.8). It is noteworthy that the furrow area did not increase with speed for this soil. When however the moisture content of the soil was increased (soil 1C) the draught force was markedly dependent on speed. Inertial forces accounted for only a small part of the increase. The furrow area increased by less than 30% which would also account for a further part. Increasing soil shear strength must therefore be the predominant cause of the increase in draught.

When the soil moisture content was higher still (soil 1A and the soil bin) the draught/speed characteristic changed in shape to the form of a decaying exponential. Hence, the moisture content is seen to play a vital role in the effect of speed on draught. Whether the moisture content acts directly e.g. say, a lubricative effect at the tine/soil interface or indirectly via, say, the soil internal friction or cohesion must be the subject of further investigation.

The textural classification of the soil also affected the shape of the draught/speed characteristic. The difference between the curves of Fig.9 (soil 2) and Fig.5 (soil 1A) is very significant.

Results have been presented, covering a wide speed range, which show that a complex model will have to be developed to embody all the pertinent parameters affecting the change of draught force with speed of simple tines.

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TABLE 1. Soil Properties

	Soil bin		1A		1B		1C		2A		2B	
	mean	s.e.	mean	s.e.	mean	s.e.	mean	s.e.	mean	s.e.	mean	s.e.
Soil type	sandy clay loam		sandy clay loam						sandy clay loam			
% clay	22.8		22.8						19.9			
% silt	21.4		21.4						5.1			
% sand	55.8		55.8						75.0			
plastic limit %	22		20						–			
liquid limit %	26		28						–			
moisture content % d.b.	14.0	0.1	18.8	0.4	3.3	0.1	14.8	0.3	11.8	0.3	11.1	0.1
density, kgm^{-3}	1775	10	1980	10	1793	30	1840	10	1890	17	1903	11
cohesion, kPa	26.6	1.2	33.4	1.3	34.2	1.3	27.6	1.5	41.4	4.4	49.5	3.8
angle of internal friction, deg.	32.8	1.8	43.9	1.5	50.8	1.9	37.1	1.6	39	5.5	35.3	2.7
angle of soil-metal friction, deg.	24.3		28		24		–		40.3	5.3	30.2	0.7

TABLE 2. Cone Penetration resistance in MPa

Soil	bin	1A	1B	1C	2A	2B
Depth, mm						
5	0.42	1.62	0.23	0.11	0.06	0.04
75	0.71	1.69	2.75	0.92	0.45	1.95
150	0.71	2.02	–	1.31	2.01	2.45

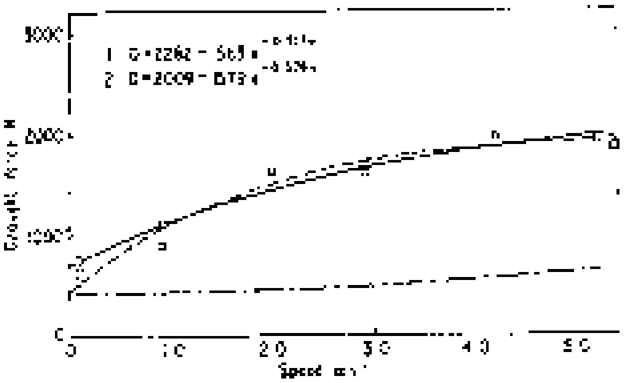

Fig 1 Draught – Speed Characteristic in Soil Bin
45° Rake Angle Tine

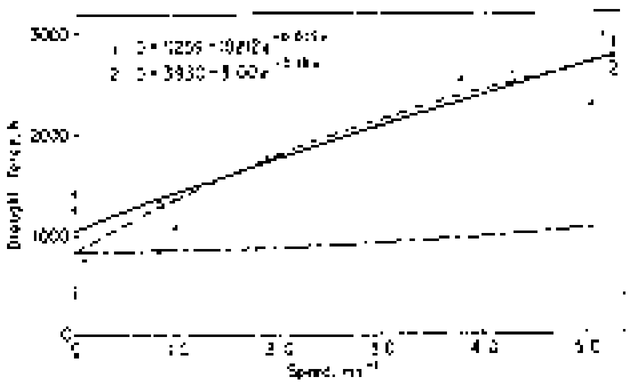

Fig 2 Draught – Speed Characteristic in Soil Bin
67° Rake Angle Tine

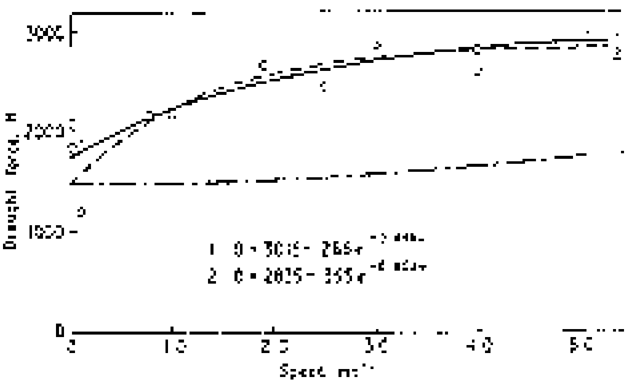

Fig 3. Draught – Speed Characteristic in Soil Bin
90° Rake Angle Tine

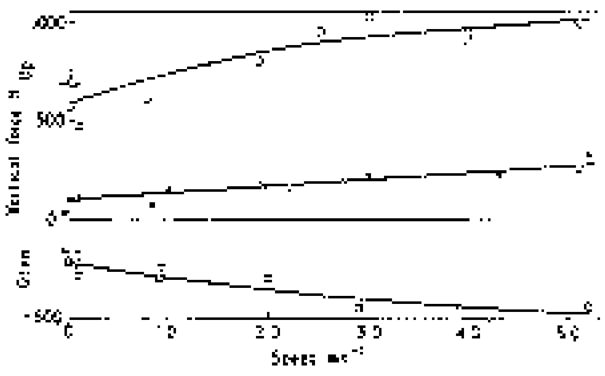

Fig 4. Vertical Force-Speed Characteristic in Soil Bin
Rake Angle of Tine ◻ – 45°, × – 67°, ○ – 90°, — – Calculated Force

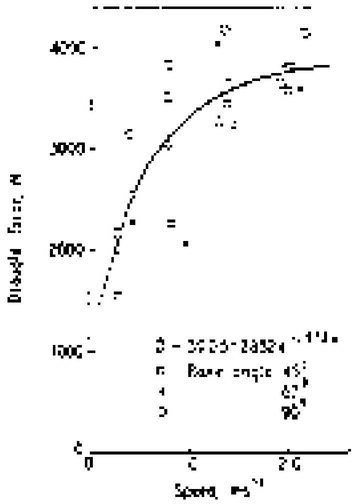

Fig 5 Draught – Speed Characteristic for Soil 1A

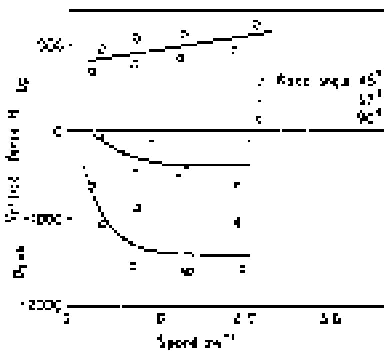

Fig 6 Vertical Force-Speed Characteristic for Soil 1A.

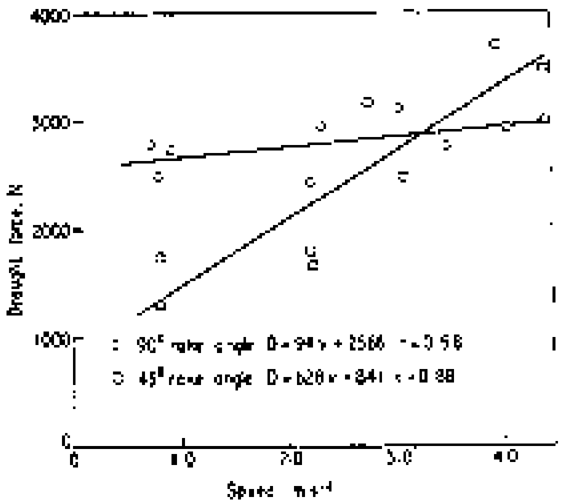

Fig. 7 Draught - Speed Characteristics for Soil 1C

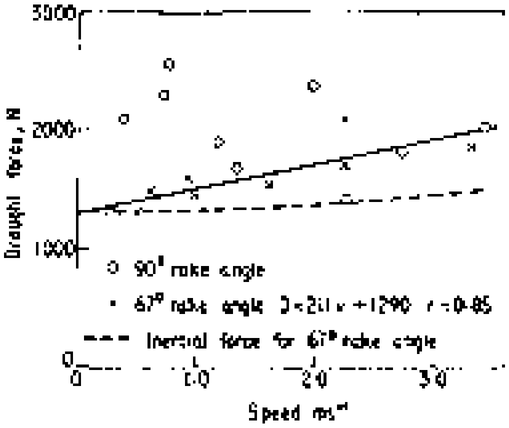

Fig. 8 Draught - Speed Characteristic for Soil 1B

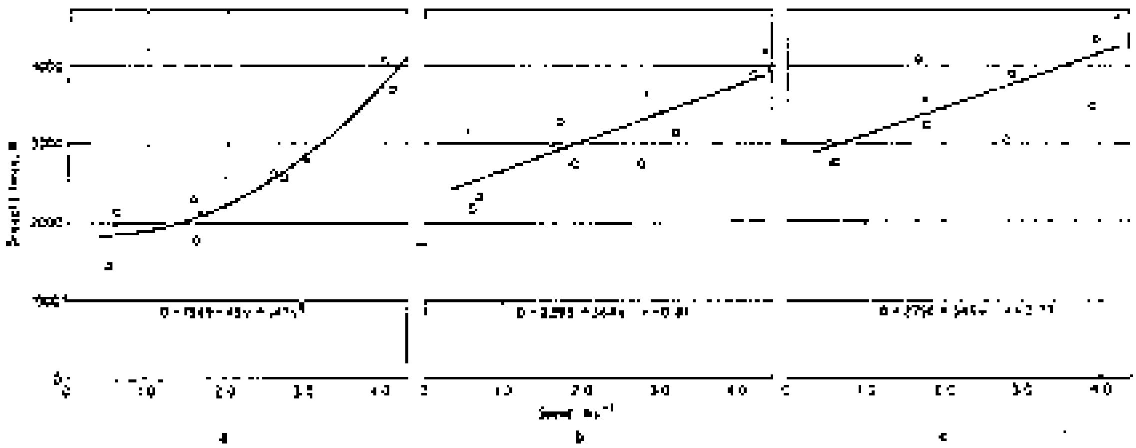
Fig. 9 Draught - Speed Characteristics for Soil 2. Rake Angle of Tine a 45°, b 67°, c 90°. x = Stubble, ○ = Fallow, — = Calculated

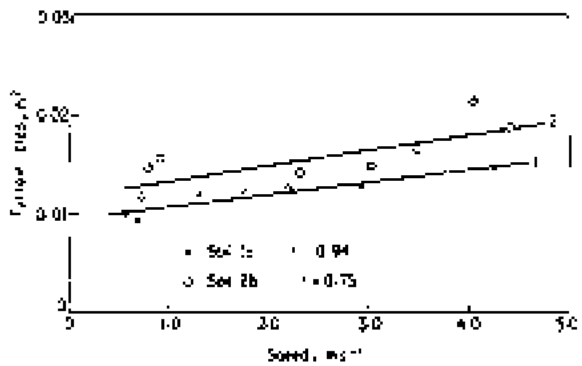

Fig. 10 The Effect of Speed on Furrow Cross Sectional Area

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SUBSURFACE DRAINAGE, TILLAGE LAYER COMPACTABILITY AND COTTON RESPONSE TO SEEDBED COMPACTION IN A CLAY SOIL

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ABSTRACT

Subsurface drainage of the cotton seedbed in a semi-humid climate is assumed to reduce the resettling of the tilled soil during winter, and its compaction during seedbed preparation in spring. The latter assumption was tested in an irrigated-cotton experiment carried out under "wet spring" conditions, in a drained and in an undrained block. Soil compaction was found to be a function of subsurface drainage and of surface drying conditions; the theory of its dependence on soil water suction was reconfirmed. Depth of the dry surface layer was found to be an easy measurable parameter which may serve to characterize soil drainage and compactability conditions. Cotton responded to compaction beneath wheel tracks by a change in rate and character of growth, similar to its response to plant stand. Subsurface drainage resulted therefore in earlier ripening of the cotton and a somewhat higher lint percentage.

INTRODUCTION

In the northern valleys of Israel the climate is semi-humid, with 450-650 mm winter rainfall. The main crop is cotton, planted during the first half of April in a seedbed which had been prepared in autumn. Farmers claim increased cotton yields due to sub-surface drainage of the heavy grumusol soils, but analysis of rainfall-drainflow data by Steinhardt et al.(1972) has shown that there exists only a 90%, 63%, 42% and 11% chance of obtaining a significant drainflow during the months January to April, respectively. This situation almost excludes direct effects of subsurface drainage on cotton yields.

The quantitative analysis of the possible mechanisms by which subsurface drainage may affect, directly or indirectly, cotton yield is the basic problem of our research; its solution might lead toward a rational design of drainage and tillage operations.

Hitherto, the "trafficability approach," assuming tractor bog-down in undrained soil, was suggested as a basis for cotton field drainage design (Nadel,1969). This approach may be valid in humid regions (Hakansson,1960; Reeve & Fausey,1974), but in the area concerned trafficability problems were solved recently; mainly by surface levelling. Concerning ourselves with soil structure rather than the tractor, we developed the "compactability approach" to the problem (Steinhardt et al.,1972; Steinhardt & Trafford,1974; Steinhardt,1974). Applying this approach to cotton, it is assumed that drainage conditions during the period between tillage in autumn and plant emergence in spring, may bring about appreciable changes in soil structure. It is assumed that soil water suctions affect soil strength, which in turn controls the resettling of the tillage layer and its compactability during cultivation and planting. These structural changes may affect cotton growth and yields directly and also indirectly, by initiating subsequent biotic and physical processes within the soil (Bertilsson,1971). Long-term changes in soil structure may be the final outcome, as may be inferred from (a) drainage experiments in humid regions (see review by Steinhardt & Trafford,1974; Hundal et al.,1975); and (b) soil compaction experiments (Vomocil and Flocker,1965).

This "compactability approach" may seem obvious to those concerned with tillage and compaction in relation to soil water content, but, astonishingly, Larson & Allmaras (1971), reviewing management factors related to soil compaction, did not even mention subsurface drainage as a management factor. Steinhardt & Trafford (1974) found that a 10 mbar rise in soil water suction, in the 2-24 mbar range, affected tillage layer compaction as a reduction in tractor wheel pressure of 1 bar (average relative effect beneath and beside the tracks). Steinhardt et al.,(1975) found that subsurface drainage almost eliminated the resettling of a tilled grumusol, due to a reduced duration of water table rise into the tilled layer, from 48% to 17% of a 2.5 month rainy period.

The "compactability approach" was tested in an irrigated cotton drainage experiment (Steinhardt et al.,1976), the essential aspects and results of which are given below. The cotton response to drainage and compaction is described in essence only, emphasizing points of interest to tillage research in general. With respect to the cotton crop, it should be noted that (a) cotton is rather insensitive to soil aeration and may withstand a few days of flooding (Letey et al.,1962). (b) deficient aeration may affect root growth without affecting shoot growth (Leonard & Pinckard,1946); and (c) irrigated-cotton yields in fine-textured soils are generally not affected by tillage and compaction (Carter et al.,1965).

METHODS

The experiment was conducted in a commercial field on 65% clay grumusol, in two adjoining blocks: one block drained by means of 24-m apart 1-m deep plastic, gravel covered, drains (DB); and one undrained block (UB). Nine 18 x 30 m plots were established in each block. The preceding crop was chick-peas. The soil was plowed to a depth of 35 cm and disked in August. Rainfall up to the beginning of March was 500 mm, well distributed and not causing any appreciable drainflow. The soil was cultivated during March, tracks being marked every second plant row space. The spring was unusually dry and hot. Differential wet spring conditions were established artificially, by sprinkling the experimental plots with 80 mm "rain" 17, 11 and 7 days before planting. Each treatment was replicated three times per block, in a Latin square design. Cotton (var.Acala SJ-1) was planted on 14/4/75, 12 seeds per m, 5 cm deep, in rows 1 m apart, utilizing auxiliary tracks on the tractor's rear wheels and a planter with "compaction" wheels exerting an estimated pressure of 0.5-0.9 bar. The crop received a pre-germination irrigation, and the customary two interrow cultivations and four irrigations. Two strips of three plots each, adjacent to the experimental blocks, served as a "dry spring" control.

One day before planting, soil water conditions were characterized by measurements of (a) soil water suction at 15 cm depth, with a quick-response portable tensiometer; (b) soil moisture percentage in the 5-10-cm layer; and (c) the depth of dry surface soil (dry mulch). About 11 days after planting, tillage layer bulk-density, water tension and content, and air content were determined below the seeds and beneath the tracks, with the aid of a "Gamma double probe" (cf. Steinhardt, 1975; Soane et al.,1971). Emergence, height increment,nutrition and yield components of the cotton were monitored. Plants from a 1-m length of row were sampled at the end of the experiment. These samples were too small to represent the plots but, analyzed simultaneously, they were considered to represent the respective blocks. Various regressions between plant and soil variables were calculated for all 18 plots, disregarding their separation into blocks. This analysis could be misleading as differences between blocks may exist. Still, it is considered to be unbiased, for two reasons: (a) identical yields of cotton and wheat were obtained in these blocks during three seasons; and (b) identical clay contents and bulk densities were measured in the tillage layer in the uncompacted cotton row space of the two blocks.

RESULTS AND DISCUSSION

A. Soil water conditions at planting time. Water suctions (S) of 50-120 mbars (423 in drained control), and dry layer depths (H_d) of 0.7-5.3 cm were obtained in accordance with treatments applied - see fig.2. The linear regression between these parameters was dH_d/dS_t= $4.4x10^{-2}$ cm/mbar; R=.66**, but testing this relationship separately in the UB and DB, respective R values were .98** and .48n.s.. These results suggest the following causal relationships: evaporation → H_d → S in the UB versus evaporation → H_d → S ← subsurface drainage, in the DB. The 5-10-cm layer moisture percentage was almost identical in all treatments, the average for DB and UB being 41.9±.2% and 42.3±.9%, respectively. This small effect, also as compared with 38.7% in the drained control, may be explained by the high clay content of the soil, causing a low "differential water capacity."

B. Soil conditions at time of emergence. Bulk density profiles in the rows are shown in fig.1. Bulk densities found in the control strips were between those of the 17- and 11-day drained treatments, suggesting that soil compaction in the cotton row was practically eliminated by these treatments. This was not the case with the 7-day drained or with the undrained treatments, with the exception of the ≤10-cm depth in the 17-day undrained treatment. In the UB at a depth >10 cm, compaction of the 7-day treatment was less than in either drier treatments (see also fig.2). A similar reversal of the drainage effect was obtained under unplowed conditions by Steinhardt & Trafford (1974). It may be assumed accordingly that the "S-min" value under these circumstances is about 50 mbar, compared to 10 mbar found in the wicken clay (cf. Steinhardt, 1974; a higher S-min means an increased danger of soil puddling under wet conditions).

Results beneath tracks were similar to those obtained in the row, but density differences between treatments were negligible compared with the difference between blocks of $7.4±1.2x10^{-2}$g/cc. Soil water suctions below seeds, both values and their variance were significantly higher in the DB (63-103 mbar) as compared to the UB (37-43 mbar). The range of air contents (cc/cc) was .12-.22 in the DB, and .04-.12 in the UB.

C. Tillage layer compactability. The regressions for each block between tillage layer bulk density and S and H_d were not significant, except in the row of the DB where dB_r/dH_d=$-2.3x10^{-2}$ g/cc; R=.69*. These results are disappointing, but rather expected when taking into account the variability of the drainage conditions applied. The same regression calculated for both blocks simultaneously are presented in fig.2. These results may be compared with those obtained by Steinhardt & Trafford (1974) in a plowed clay soil, by utilizing the relationships between suction and bearing capacity developed by Steinhardt (1974). We estimate two values: (i) the relative value of the bearing capacity-suction factor (N_s) from the difference in the plasticity index (25 in the grumusol, 8 in the wicken clay) is .645, it being implied that mode of failure, shape, depth and desaturation factors, were similar; and (ii) the dB/dS value for the wicken clay from the experimental results of dD/dS and dB/dD is $2.55x10^{-3}$ (D=wet density), and arrive at the predicted dB/dS for the grumusol of $≈1.65x10^{-3}$. This value is close to the range of $1.3-1.6x10^{-3}$ actually obtained.

D. Long-term structural changes. In preliminary measurements, which have still to be verified, the plasticity index of the soil determined after the experiment, was found to be appreciably lower in the UB as in the DB. Cotton plants in the UB withdrew more water from the soil due

Fig. 1 - Soil density in the row, as a function of depth, in drained (O) and undrained (●) blocks; averages of treatments (=17, 11, 7 days from "rain" to planting).

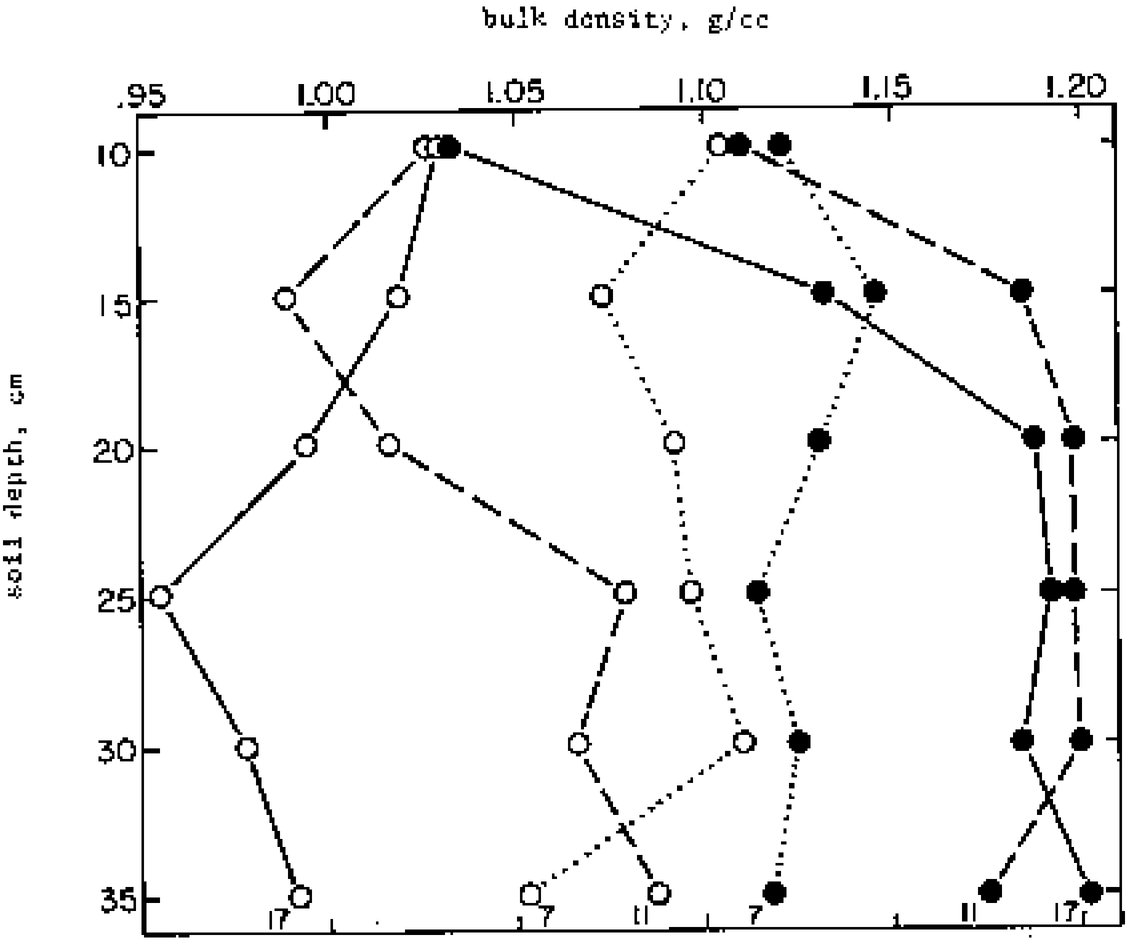


Fig. 2 - Tillage layer density in the row-B_r (lower points), and beneath wheel track-B_t (upper points), as a function of (a) soil water suction and (b) depth of dry surface layer. (Regressions are for 18 plots, only treatments averages are shown; Δ = drained control.)

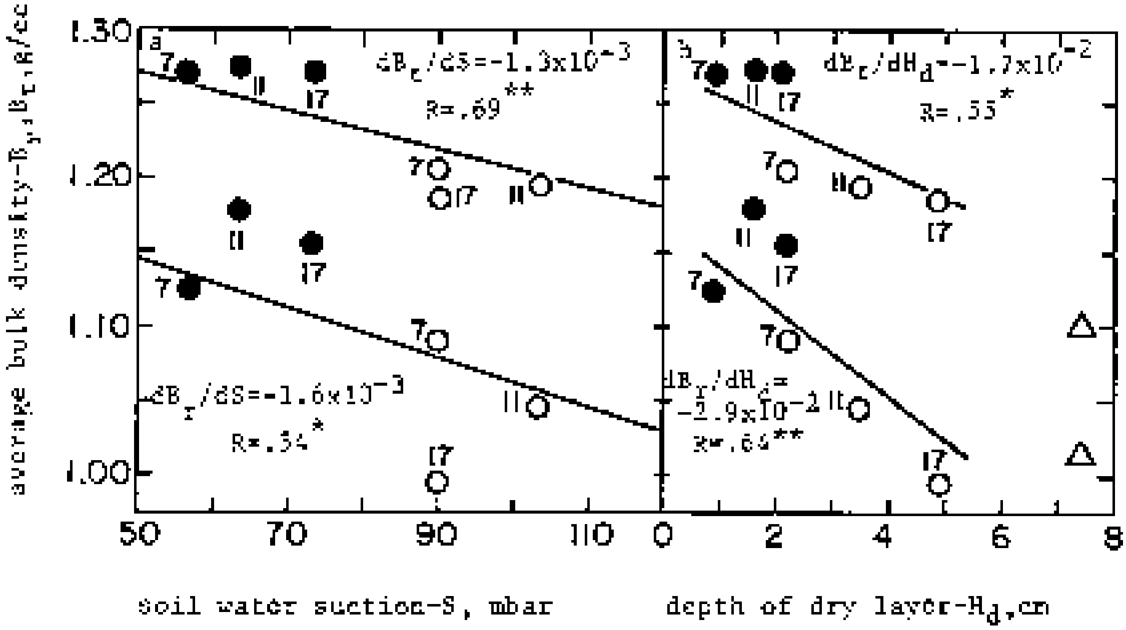
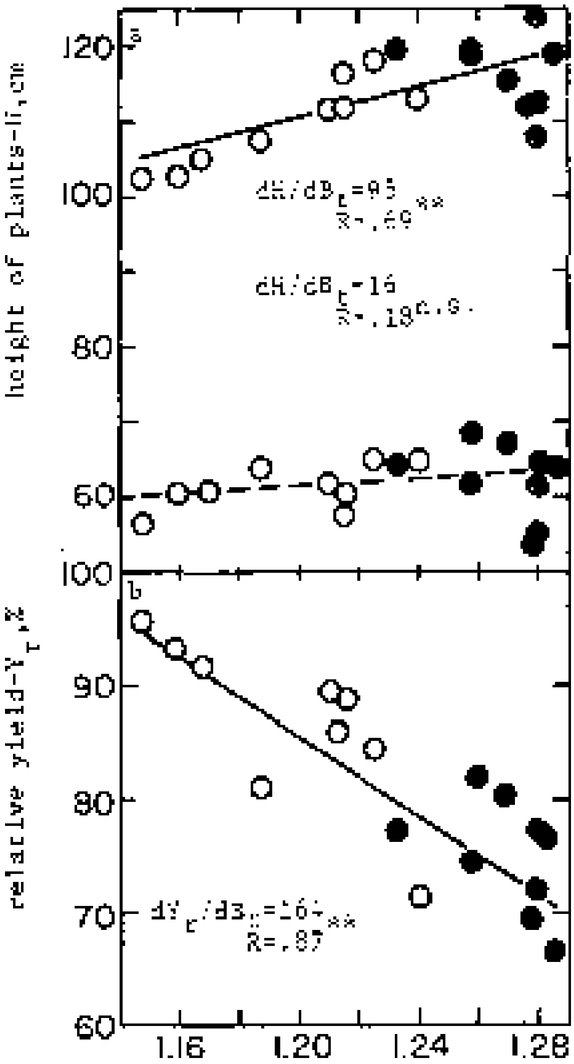
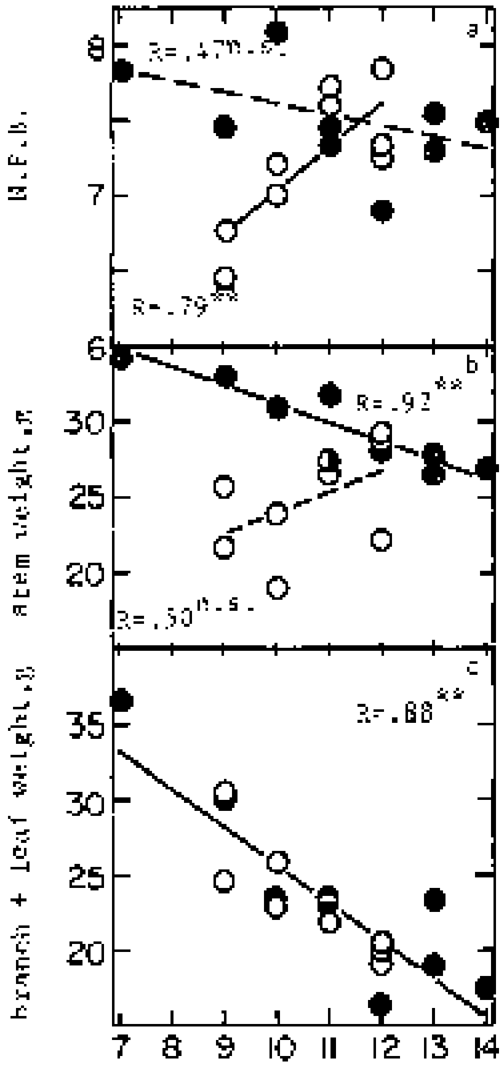


Fig. 3 - Effect of track density (B_t) and drained (O) and undrained (●) conditions: (a) plant height on June 25 and July 24; (b) relative yield at early picking. (Final yield=5626kg/ha =100%; C.V.=4.4%.)

Fig. 4 - Average values per sample of (a) node no. of first flower branch, (b) air-dry stem weight, and (c) air-dry branch + leaf weight, as functions of the cotton plant stand and of drainage conditions.





to differences in rooting and a longer growing period - see next para. Therefore, the decreased plasticity might be an indirect effect of the drainage (cf. Warkentin & Bozozuk, 1961).

E. Cotton growth and yield responses to soil conditions. Cotton response was analyzed by regression to soil variables at planting time. The results for two plant parameters are shown in fig.3. The correlations between relative early yield and other variables were (R=).73 with S, .70 with A_r, .68 with W_r, .66 with H_d, and .65 with B_r. The higher correlation with B_t of .87, as well as other results (see below), suggest that plant response was mainly a function of track compaction. An exception was a retardation in rate of emergence which could be related to air content in the row (cf. Steinhardt, 1975). Final yields in the blocks and the control strips were almost identical. But, due to the differential time of ripening the weighted lint percentage in the DB was 38.4%, vs. 37.8% in the UB, a small but significant difference. Water content in the tillage layer on the uncompacted side of the rows (W_u) was found to be lower, the higher the compaction on the other side: dW_u/dB_r=-.52; R=.66**. Although this result has not been verified directly, it suggests greater root proliferation as a compensation for the unfavorable root growth conditions to the other side of the plants. An equivalent root growth response was obtained by Taylor & Burnett (1964).

An interesting insight into the possible causal relationships is gained by the analysis of plant samples, results of which are shown in fig.4. The identical branch-leaf weight response to plant stand (a random variable) suggests that there was no difference in shoot competition for light between the UB and DB, as also suggested by the uniform final yields. In contrast, the differences in response of the main stem development parameters to plant stand suggest quite clearly that competition between roots of adjacent plants is similar in effect to soil compaction. One has only to shift the regression lines for the UB by 6 to 8 plants per m to the right, to see the similarity with the height response to B_r, shown in fig.3a. The results of Greacen et al.(1969), demonstrating the difficulty encountered by roots trying to enter compact soils at incidence angles greater than 45°, and the assumption of a geotrophic effect on root growth, explain the rather high sensitivity to track compaction implied.

Although final cotton yields were almost identical it should be possible to assess those circumstances in which yields will differ appreciably; that is the circumstances in which cotton plants will not be able to change their rate and mode of development without yield reduction. Deficiencies in nutrient or water supply, and an insufficient growth period, are obvious examples of widespread occurrence. The claim of farmers that cotton yields respond to subsurface drainage has thus been warranted. Following some additional research it should not be too difficult to predict this response quantitatively.

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The 7th Conference of the International Soil Tillage Research Organization, Sweden, 1976

A new Machine for the Insertion of Straw into the Soil and for deep Tillage in ploughless Tillage Systems

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Abstract:

Within the scope of an extensive research programme in the University of Hohenheim several problems of process engineering of cereal products are tackled. A part of this research programme deals with investigations into problems of soil tillage and of drilling cereal grains. A practical research result in this field has led to the development of a new machine whose prototype has been tested. This machine is able to perform the following functions: insertion of straw and stubble into the soil; deep break of soil instead of ploughing; and seedbed-preparation, if drilling follows immediately after the deep tillage. This report gives a summary of some of the considerations which led to the construction of the machine. Details of the machine design and some of the experimental results are also given.

The ploughless cultivation and the insertion of straw into the soil are investigated on together by the Institutes of Agricultural Engineering and of Plant Production within a special research programme called "Process Engineering in the Production of Cereals". The aims of the investigations of the practical research are to develop efficient machines and methods which would not decrease crop yields or have adverse effects upon the environment. In this connection not only conventional machines are being tested, but also new tools and implements are also being developed and built, if they promise to be successful. Some of the conventional machines and methods as well as the newly developed machines are being tested in long-term experiments at different parts of Germany. From these experiments, the machines and methods are compared with regards to their effectiveness, efficiency, power requirement and their influences on crop yield environment. In the following paragraphs a report wi.

be given about the machine which has been developed within our research work and which has been tested last year for the first time. The main reason for developing this machine was the search for an optimum method to insert straw into the soil, because this is a topical subject in Germany at present. One can say that straw is properly inserted into the soil when only very small quantities of straw remain on the soil surface. Under conditions of well inserted straw into the soil, problems arising from seed drilling which would follow this ploughless cultivation are unlikely to occur. Also the straw is expected to decay fast to avoid a decrease in crop yield.

Little information is available on the depth of straw insertion into the soil and on the maximum straw concentration in the soil as they are affected by various parameters such as soil and climatic conditions. Some experiments have been carried out on straw decay. The results of these experiments have been used as the basis for the development of the machine. The results which are important in this connection are given in Figure 1. This figure shows that the greatest amount of straw decays when the straw is uniformly inserted into the soil up to depths corresponding to 20 cm. Therefore the developed machine for straw insertion had to fulfill the following condition: it must mix the straw with the soil up to depths of 20 - 25 cm so that the straw concentration might be evenly distributed all over the depth of insertion.

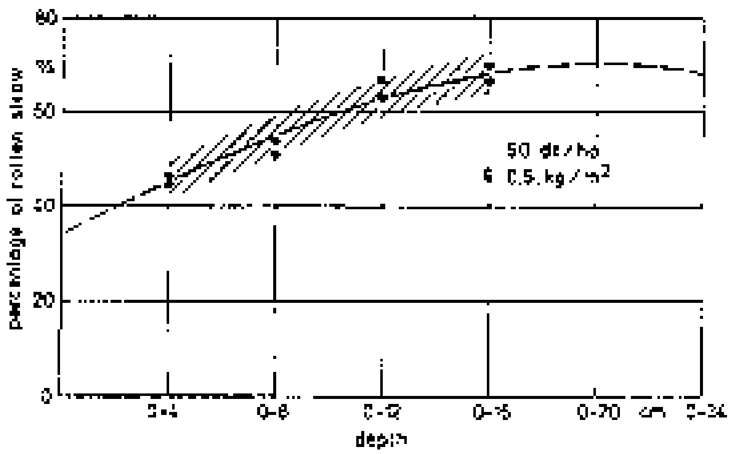


Figure 1: Effect of depth of straw insertion on straw decay (after seven month)

For cereal production in primary cultivation which reqires a soil break of 20 - 25 cm this machine should be able to substitute the plough. In those cases, in which drilling takes place immediately after the insertion of straw and after deep break (winter grain following corn, lucerne or clover following grain) the machine should also be able to prepare the seedbed in the same pass.

Figure 2 shows the schematic diagramm of the test machine. The machine consists of a basic frame (1) which is fastened to the three-point-linkage of the tractor. Firmly connected with the basic frame is a row of horizontally arranged heavy cultivator tines (2) and a rotary cultivator (3). The rotary cultivator can be adjusted in vertical direction so that depth of tillage can be changed relative to the depth of the heavy cultivator tines. The heavy cultivator tines as well as the rotary cultivator can be adjusted independent of each other in horizontal direction, in order to reach an optimum mixing and tillage effect. Important for the work of the heavy cultivator and rotary cultivator combination are the arrangement in longitudinal direction and the shape of the heavy cultivator shares, because the heavy cultivator is to produce a soil stream of coarse clods, which flows into the rotary cultivator and is shared there. As the heavy cultivator transports the soil out of depths up to 25 cm, the rotary cultivator cuts more soil particles than it would normally do. At the

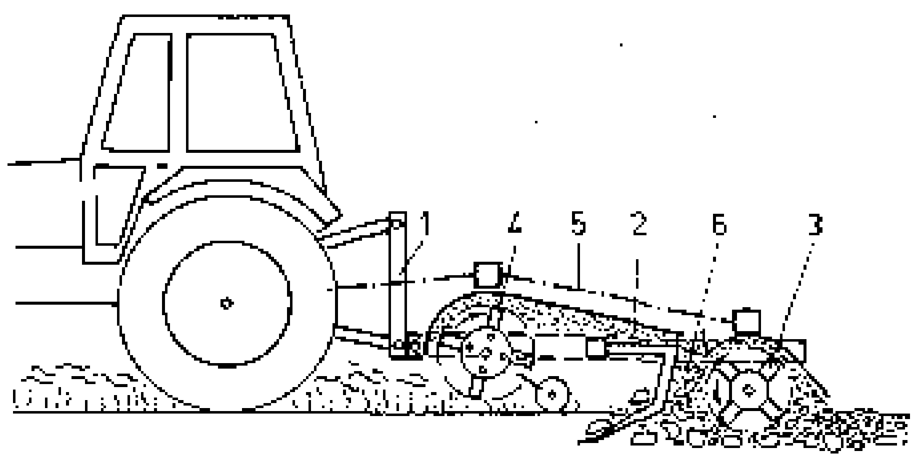
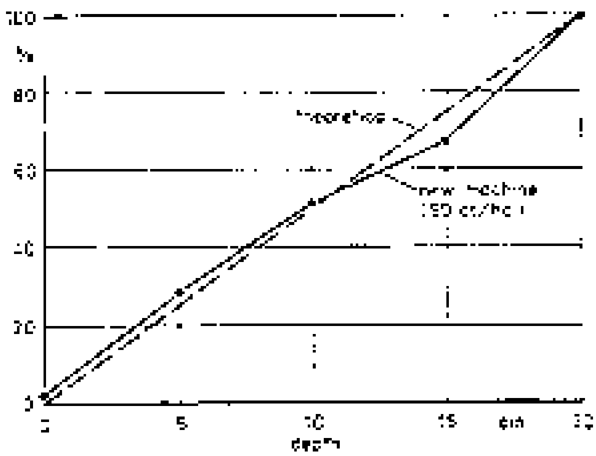


Figure 2: Schematical diagramm of the test machine

front part of the frame a flail type forage harvester (4) is fastened by joints. The flail type forage harvester can move vertically independent of the basic frame and is able to adapt itself optimally to the ground by means of wheels. The flail tools chop the straw and the stubble and throw the chopped straw behind. Thereby the straw is transported on guide plates (5) into a kind of mixing room (6) where it can premix with the soil particles that have been thrown up by the heavy cultivator tines and by the rotary cultivator. Part of the straw falls into the created hollow space and thus gets to the working depth of the tines. In the upper layer of about 8 cm the rotary cultivator causes further intense mixing and leaves a well crumbled and even surface. The distribution of straw in the working depth can be regulated to some extent: firstly by the guide plate which can direct the flow of straw depending on its regulation either more to the heavy cultivator tines or to the rotary culivator. Secondly the distribution of straw is influenced by the working depth of the rotary cultivator.

A result regarding the quality of straw insertion of the test machine is given in <u>figure 3</u>. The sum of weight parts of straw is plotted against the depth of insertion. The broken line represents the theoretical course when in depth from 0 untill 20 cm the straw was inserted quite uniformly, that is when the same straw concentration exists at every place of the working depth. The solid line shows the course



<u>Figure 3</u>: Curve of the cumulative weight parts of straw, which was inserted by the new machine, as affected by the depth of insertion

for the new straw insertion machine at 50 dt/ha. The results show that the new machine inserts the straw into the soil very well up to depth of 20 cm. Furthermore one can see that very little straw remains on the surface (depth = 0 cm).

At present nothing can be said about the results regarding primary cultivation, because the new machine has been used on our experimental fields last year for the first time. On these fields the new method will be compared with several other methods in long-term experiments, on the basis of the total amount of straw inserted into the soil. The crop rotation in these experiments is corn - winter wheat - spring barley. The scale for comparison is the crop yield.

In the experiments of the previous year the machine achieved a well crumbled and even surface which immediately could be used as seedbed. Thus last year winter wheat could be drilled after the corn straw had been inserted.

The specific problems of this combination may certainly not technological ones. Through optimization of the design of the machine it may be possible to improve the results of the first experiments: results that anyhow are rather satisfactory. The main problem centres around keeping the required power as low as possible. The working width of our machine is 1,8 m. This machine uses five cultivator tines. For a cultivator tine depth of 20 cm and for a working speed of 5 - 6 km/h, the power required may be as much as 120 tractor-HP.

It has been found out that the energy requirements of the combined system is lower than the energy requirement of separate successive passes. However the power requirement of the combined system is rather high because its working width has to cover the total width of a 1800 mm-track tractor with 15 inch-tires. Therefore the machine parts must be optimized in order to minimize power requirement.

There are a number of possible ways to do this: the straw chopper need not revolve at the usual high number of revolutions, because the straw need not be spread so far from the machine. The distance between the heavy cultivator tines can be made greater than that of a normal heavy cultivator. It should also be possible to improve upon the design of the knives of the rotary cultivator more to get lower power requirement. In spite of all these optimizing measures, a tractor power of more than 100 HP at a working speed of 6 km/h will be necessary.

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THE EFFECT OF SOIL COMPACTION ON ROOTING PATTERNS AND WATER UPTAKE OF COTTON

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ABSTRACT

Compacted layers in soil reduce water and air movement through the layer and increase the chances that plant roots will be slowed down or completely stopped by the soil pan. The compacted layers will cause greater quantities of roots to be present above the layer and will reduce the density of rooting below the layer. Because water uptake rate from a soil layer is proportional to rooting density, water uptake from all layers below the pan usually will be slowed. This reduced water supply usually reduces yield. However, in some dry climates, the reduced rate of water use sometimes will assure sufficient water for some yield, but the amount of yield will be greatly reduced.

The radicle of a cotton plant can elongate at rates up to 3 mm/hr under ideal conditions (Pearson, Ratliff, and Taylor, 1970). This elongation rate can be maintained until lateral roots are initiated on the primary root (personal observation). The root elongation rates can still be rapid after lateral initiation.

Cotton roots grew to a 160 cm depth 42 days after planting (Taylor, Huck, and Klepper, 1972). Considering the time lag for radicle initiation, this root elongation rate was greater than 4 cm/day. Thus, cotton plants have the genetic potential for rapid root elongation rates if their root environment is ideal and the photosynthate supply from the tops is satisfactory.

However, cotton root systems seldom encounter an ideal soil environment for long periods and often must overcome a distinctly adverse environment soon after the radicle emerges from the seed. These adverse conditions are frequently due to soil compaction. Soil compaction has decreased crop yield on an estimated 0.8 million ha of land in California alone (Gill, 1971). Soil compaction affects root growth of cotton at many locations in the southern and southwestern United States (personal observation). Most of these soil compaction problems on root growth are found in loam or sandy soils.

Compacted soils have greater soil strengths than uncompacted soils at the same water contents (Taylor and Gardner, 1963). Soil strengths are increased still more as the compacted soil dries from field capacity to the wilting point. This usually explains the effects of soil compaction on growth of cotton roots in sandy soils (Taylor, Mathers, and Lotspeich, 1964).

The high-strength (compact) layers caused the greatest decrease in yield when they were located nearest to the soil surface in these sandy soils (Lowry, Taylor, and Huck, 1970).

Some of these shallow, compacted layers damage cotton roots by strangulation. The radicle exerts enough force to penetrate the moist compact layer. However, when this layer dries, the primary root cannot exert enough force to expand radially. If this condition continues for 3 or 4 weeks, transpirational demands of the shoots exceed the capacity of the constricted portion of the main root to carry enough water upward. Thus, the plant wilts or dies. This condition has been described in detail by Taubenhaus, Ezekiel, and Rea (1931) and by Taylor et al. (1964).

Another mechanism through which these high-strength, compacted layers decrease yields is by decreasing total rooting depth and, thus, by decreasing total water supply. In an experiment at Auburn, Alabama, Lowry et al. (1970) investigated the effects of the depth and bulk density of the soil pan on a loamy sand on cotton growth rate and yield. They found that yield increased (at a particular bulk density) as the depth to pan increased. At any particular depth to pan, yield decreased as bulk density increased. They found that plant height on July 3 (a time of rapid cotton boll formation) linearly increased with the percentage of available water that had been extracted from the soil at a depth 10 cm below the soil pan surface.

Cotton roots extract water from a soil layer in direct proportion to the rooting density (cm root/cm^3 soil) and to the water potential difference between bulk soil and root xylem. Water extraction rates are inversely proportional to the resistance encountered by the water in moving from bulk soil to root xylem (Taylor and Klepper, 1975).

A compacted layer can change rooting density substantially in all layers in which roots would be found in the normal circumstances. The compacted, high-strength layers usually cause rooting density to increase in all layers above the compact one and to reduce within the compact layer and all layers below it (Taylor et al., 1972). This causes the cotton plants to extract water faster than normal from above the compact layer and slower than normal from below the compact layer, when compared with plants grown under the same climatic environment but in a soil with no compact layer.

As shown by the experiment of Lowry et al. (1970), the plant's ability to extract water from below the soil-compacted layer usually will increase water supply, growth rate, and yield. Sometimes, however, a decreased water extraction rate from deep within the profile is advantageous; for example, when the cotton plants must mature on stored water, with very little probability of precipitation during their boll formation and maturation period. Under these conditions, a decreased rooting density below the soil pan would cause a decreased growth rate of the plant shoots. This decreased shoot growth will decrease transpirational demand enough to allow the stored water to be used longer. This lengthened time will allow the plant enough time to produce some yield, even though the yield level will be substantially decreased from that expected had the water supply been adequate.

Cotton yields usually are increased when compacted soil layers are disrupted by any tillage method (Burleson, Bloodworth, and Biggar, 1957; Carter and Tavernetti, 1968; Hendrick and Dumas, 1969). The magnitude of the yield increase caused by tillage will vary with the intensity and depth to the soil pan under any particular climatic environment. Yield increase caused by tillage also will vary with climatic conditions. If the tillage operation does not cause more water to be available to the cotton plant for its growth, the tillage operation usually will not increase yield.

Many acid soils in the southeastern United States contain toxic quantities of aluminum in the soil solution, especially the more acid subsoils. These toxic aluminum levels will prevent or slow root development into the subsoil, even though there are no compact layers. Therefore, disrupting compacted layers will not increase yield on these soils, unless this excess acidity is corrected by adding lime to all soil volumes where root growth is needed.

Persistence of the yield increases caused by disrupting compacted layers will vary with the soil type and with its management. Research workers in the southeastern United States have developed a controlled traffic technique, where the tractor tire paths are confined to permanent strips within the field. This allows management of the pressure that machine tires exert on the soil, so that the traffic interferes as little as possible with plant growth. In one experiment at the National Tillage Machinery Laboratory at Auburn, Alabama, the soil was tilled by chiseling to 45 cm. Cotton yields were increased about 300 kg/ha. However, once traffic was allowed on the 45-cm-deep root bed, the difference in cotton yields decreased rapidly. In later tests in which all variables except traffic were kept constant, plots with controlled traffic produced about 3600 kg/ha of seed cotton, while plots with unrestricted traffic produced only 3000 kg/ha--almost 20% difference in favor of controlled traffic (Trouse, Dumas, Smith, Kummer, and Gill, 1975).

In summary, compacted layers in soil decrease cotton yields each year on large areas in southern and southwestern United States, usually because they reduce the total quantity of water supplied to the plant tops. Cotton yields are increased when these compacted layers are disrupted if this disruption will increase the total water supply available to the roots. On certain soils, adverse soil chemicals, such as aluminum, must be changed before the water supply and yield will be increased. Often, the compacted layers will reoccur rapidly unless tractor-tire traffic is restricted to specific paths.

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PLANT RESPONSE TO WHEEL-TRAFFIC-INDUCED SOIL COMPACTION IN THE NORTHERN CORN BELT OF THE UNITED STATES.

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ABSTRACT

Plant growth response to soil compacted by wheel traffic during normal field operations depends on the interaction of soil type, plant species, and climate. In the Northern Corn Belt of the United States, (about 45° N latitude), germination and early growth of corn and soybeans are often limited by suboptimum soil temperatures. Later, growth is often limited by water deficiency. Field studies in Minnesota show that soil temperatures and water use efficiency both decrease and increase in response to wheel traffic. This parabolic plant response suggests ways of controlling soil compaction and root growth to increase fertilizer use efficiency and maximize crop yields.

INTRODUCTION

Most of the research on plant response to wheel traffic in the United States has been conducted in the southern and coastal areas. These soils are frequently low in organic matter and inherently lack the structural stability to resist deformation by intensive rainstorms and excessive tillage or wheel traffic. Consequently, traffic pans develop at tillage depth to restrict vertical root growth, and wheel traffic compacts the soil to restrict lateral root growth (Trouse, 1971). This restricted rooting volume often causes plants to be water stressed. Similar results have been reported under other temperate climates such as in India (Chaudhary and Prihar, 1974).

However, plant response to soil compaction depends on a combination of interactions between soil type, climate, and plant species (Rosenberg, 1964). Thus, plant and soil responses in the cooler, drier climate of the Northern United States may be qualitatively and quantitatively different from those in warmer, humid climates. The "Corn Belt" of the United States lies principally between 35° and 45° N latitude, and is bounded on the east and west by 80° and 100° W longitude. Most of the soils are inherently productive, medium textured, and well structured, having been developed from prairie or transitional prairie-forest vegetation (Mollisols and Alfisols). With few exceptions, root growth normally is not restricted as much as in the Ultisol soils further south. Thus, there has not been concentrated research on plant response to soil compaction in the Northern Corn Belt. This is also due in part to lack of techniques and knowledge to delineate plant responses to various aspects of soil and climatic environments. This lack of interest has been further accentuated by the presumed ameliorative effects of annual freezing and thawing, which may extend 120 cm deep in the northern portion of the Corn Belt. However, in one study in which the soil in the bottom of the plow furrow was artificially compacted, 9 years of cropping and subsequent winter freezing did not destroy the compacted layer 1/.

The current trend in the United States toward larger and heavier farm machinery, with 4-wheel drive tractors weighing more than 13,500 kg (Voorhees, 1975b), has renewed research interests on wheel-induced soil compaction in the Corn Belt. The following discussion will review on-going research on soil compaction and its observed and potential effects on plant growth in the northern Corn Belt of the United States. All reference to wheel traffic is from standard farm-sized tractors performing an average of five separate operations per growing season, with each wheel pass exerting a pressure on the soil surface of about 6 kg per cm^2.

SOIL TEMPERATURE

Heat capacity and thermal conductivity expressed on a volume basis increase as compaction increases (van Duin, 1956). But the soil temperature at a given time is also a function of the soil water content, which is mediated by compaction effects on infiltration, redistribution, and evaporation of water. Thus, soil temperature may either decrease or increase as a result of wheel traffic. In 1975, the 5-cm depth soil temperature of a wheel-tracked Forman clay loam (Udic Argiboroll) at Morris, Minnesota that was fall plowed and planted to corn (*Zea mays*) was as much as 3°C cooler than the nontracked soil throughout the growing season. At Lamberton, Minnesota, the maximum soil temperatures in wheel-tracked and nontracked soils were essentially the same in a Nicollet silty clay loam (Aquic Hapludoll). However, continuous 24-hour temperature measurements at Lamberton revealed differences in *duration* of a given soil temperature; the wheel-tracked soil accumulated 4 to 10% more degree hours favorable for germination and early seedling growth than did the nontracked soil. While this may seem insignificant, a small change in soil temperature in the Northern United States where soil temperatures at planting time average about 18°C can greatly change early corn growth (Allmaras et al., 1964) and root growth patterns (Allmaras and Nelson, 1973). This illustrates a potential effect of wheel traffic in cooler climates that is generally not considered agronomically important in the Southern United States.

SOIL WATER USE

Along with low early-season temperatures, water deficiency in the latter half of the growing season often limits corn and soybean (*Glycine max*) yields in the Northern Corn Belt of the United States. During this period, evapotranspiration from corn and soybeans commonly exceeds rainfall by 13 and 6 cm, respectively (Holt and Van Doren, 1961, and Timmons et al., 1967). Thus a small change in water storage or water use caused by wheel traffic can be important. Water-use efficiency, defined as crop yield per unit of water loss, can be calculated from data shown in Table 1. Wheel traffic increased the water-use efficiency 16% for corn, decreased it 35% for wheat, (*Triticum vulgare*) and had essentially no effect for soybeans. These examples

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1/Blake, G. R., W. W. Nelson, and R. R. Allmaras. Persistence of subsoil compaction in a Mollisol in southwestern Minnesota. Unpublished manuscript.

may or may not represent long-term averages, but they do show that plant response to wheel traffic can differ for various combinations of crop species, climatic conditions, and soil type.

Table 1. Crop yield and water loss for various crops as affected by wheel traffic.

Crop	No wheel traffic		Wheel traffic	
	Yield, kg/ha	Water loss,* cm	Yield, kg/ha	Water loss,* cm
Corn, Lamberton, 1974	5,209	18.3	5,591	16.9
Soybeans, Morris, 1975	2,014	36.7	2,179	38.9
Wheat, Morris, 1975	3,746	30.0	2,690	33.1

*Total of evaporation and transpiration, assuming no runoff.

Another complicating effect of wheel traffic in determining water use by plants is that wheel-traffic-induced soil compaction may also cause lateral movement of water (Figures 1 and 2). The tensiometric soil water suction values are the measured lateral differences at various depths between two adjacent soil profiles 76 cm apart, one wheel tracked, and the other having no wheel traffic. A row of corn was centered between the two profiles of Figure 1, and a row of soybeans was between the two profiles of Figure 2. A positive suction gradient indicates a potential gradient for lateral water movement

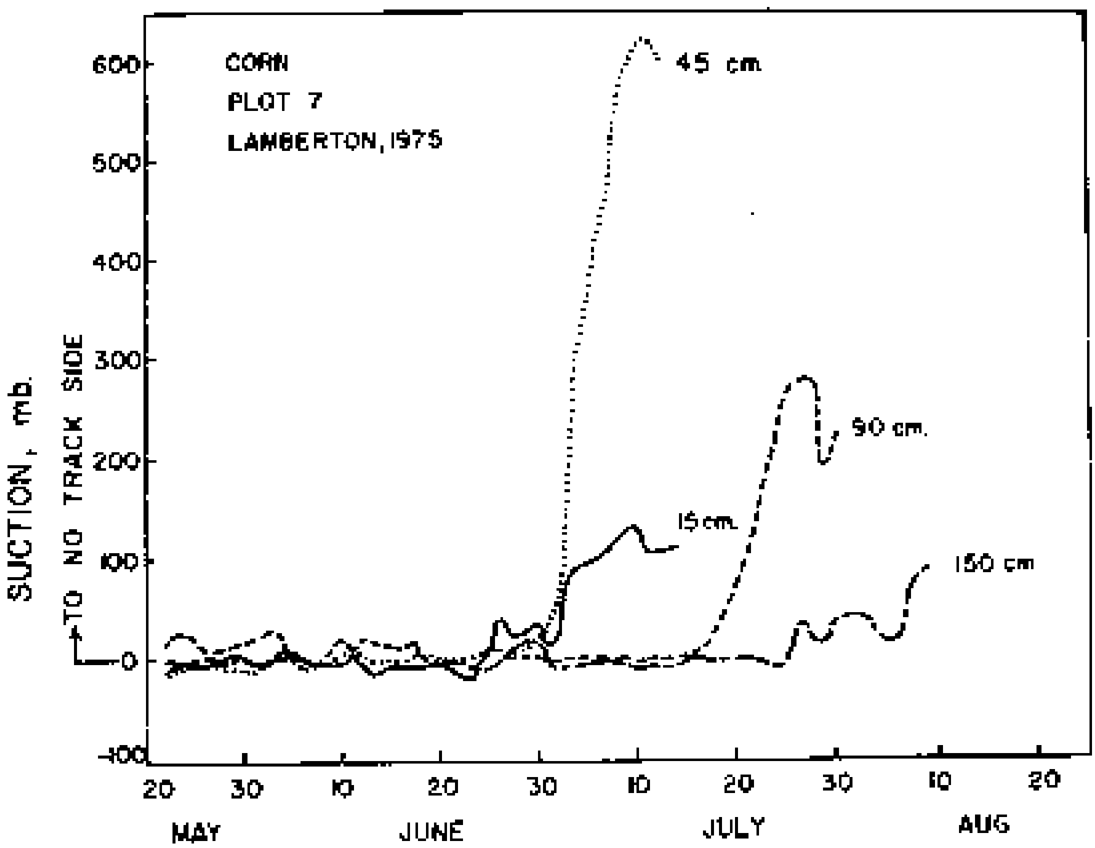

Figure 1. Lateral soil water potential gradients between wheel-tracked and nontracked profiles of a Nicollet clay loam under corn.

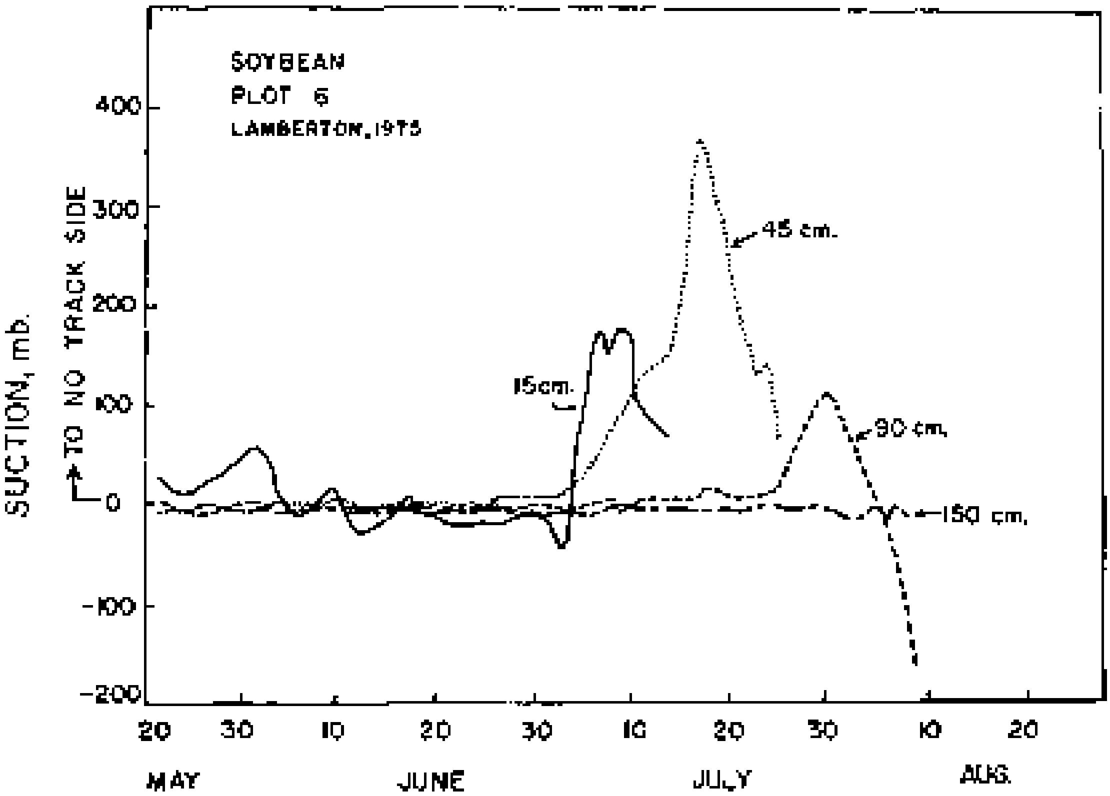

Figure 2. Lateral soil water potential gradients between wheel-tracked and nontracked profiles of a Nicollet clay loam under soybeans.

from the wheel-tracked side of the row to the nontracked side of the row; negative values indicate a gradient towards the wheel-tracked side. For corn (Figure 1), there were no lateral gradients in either direction at any of the observed depths before June 30. After June 30, there was a small gradient toward the nontracked side of the row at the 15-cm depth, and a large gradient in the same direction at the 45-cm depth. A lateral gradient in the same direction began at the 90-cm depth about July 15, followed by a similar gradient at the 150-cm depth about 10 days later. This depth progression of a lateral gradient with time probably coincides with the advancement of the root system and suggests a faster depth-wise root growth rate on the nontracked side of the row, or a more active root system in terms of water uptake. The soil bulk density at the 15-cm depth was 1.29 g/cm^3 and 1.62 g/cm^3 for the nontracked and wheel-tracked sides, respectively. At deeper depths, bulk density was essentially the same for the two sides and increased from 1.54 g/cm^3 at the 45-cm depth to 1.83 g/cm^3 at the 150-cm depth.

The sequence of lateral gradients with depth and time was similar in the soybean row (Figure 2), except the gradients were smaller and even reversed direction at the 90-cm depth. This reversal in direction may have occurred at other depths also (and also for corn in Figure 1), but measurements were limited by the air entry values of the tensiometers, about 800 millibars (mb). Unlike corn, the measurements for soybeans did not indicate any differential water uptake or movement at the 150-cm depth because of the shallower root system of soybeans.

These examples of plant response are not easily explained, and illustrate the complexity of the interaction between plant species and environment in determining the effects of wheel traffic on plant response. This agrees in part with Håkansson's observations in a similar climate in Sweden (Håkansson, 1966).

ROOT GROWTH

The increase in soil bulk density at the 15-cm depth as a result of wheel traffic increased the soil strength characteristics enough to greatly reduce corn root growth to a depth of 25 cm under the wheel track. About 60% of this surface 25-cm soil layer contained no roots. With no wheel traffic, this same soil volume had a root length density of about 1.9 cm/cm^3. While this root growth restriction may not normally subject the plant to severe water stress as occurs with similar root growth restrictions in the Southern United States, it does have significance. In the Northern Corn Belt, fertilizer is commonly broadcast on the soil surface and then incorporated throughout the surface 20- to 25-cm layer of soil by tillage. But with immobile ions like phosphorus and potassium, wheel traffic may prevent sufficient root growth to completely utilize the applied fertilizer, and yields may be reduced. If the portion of the root system unaffected by wheel traffic can supply the plants' total P and K requirements, then 60% of the fertilizer applied is not needed.

The density of individual 3-cm-diameter clods from the surface 25-cm layer of a Nicollet silty clay loam that had been wheel tracked during three successive growing seasons was 1.70 g/cm^3 compared to a density of 1.43 g/cm^3 in an adjacent untracked area. Within this range of density, root growth and phosphorus uptake from individual aggregates can be significantly affected (Voorhees et al., 1971).

Soil compacted by excessive wheel traffic can restrict sugarbeet (Beta vulgaris) rooting depth and cause deformed storage roots (Voorhees, 1975a). Potato (Solanum tuberosum) yields were decreased from 25,550 to 16,800 kg per hectare by the wheel traffic on a clay loam at Morris, Minnesota 2/.

SUMMARY

Plant response to soil compaction from wheel traffic under normal field conditions depends on a number of interacting factors. In the relatively cool spring, dry growing season climate of the Northern Corn Belt of the United States, plant response may be parabolic, such as was reported by Håkansson (1966). Compaction can increase or decrease the soil temperature, an important factor in early corn growth. Compaction can both increase and decrease water-use efficiency. Root growth may often be restricted, resulting in inefficient use of immobile fertilizer ions. Controlled traffic, whereby all wheel traffic is restricted to certain areas of a field, may be a practical way of managing soil compaction to the plant's benefit under relatively cool dry growing conditions. Research is continuing to fully assess the effects of wheel traffic on plant response in the northern latitudes.

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REDUCED TILLAGE IN SECOND CROP GROWING WITH IRRIGATION ON CHERNOZEM SOIL

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ABSTRACT

The specificity of second crop growing and their place in crop rotations under supplemental irrigation conditions permits succesfull utilization of extended effect of deep tillage carried out under winter wheat.
Hence on the soils of favourable physical properties the tillage for second crops has been reduced to a great extent thus reducing it to only seed bed preparation by discing. Zero tillage resulted in somewhat lower yields even on chernozem of excellent physical properties with irrigation applied.

I N T R O D U C T I O N

Soil is more intensively utilized by second crop growing under irrigation conditions which requires more frequent tillage compared to production without irrigation. Under conditions like that the tillage system has been somewhat changed depending on the irrigation method and primarely the tillage in second crops. The specificity of the second crops is that they have been grown in one year on the same field after winter wheat or barly as main crop. Presumably the second crop will not require the same way of soil preparation as the main crop. However, it primarely depends on the physical properties of the soil and irrigation method of the main crop. The better the physical conditions of the soil after the main crop are and the compaction less the greater changes could be expected in tillage and soil preparation for second crop.

INVESTIGATIONS AND METHODS

Investigations were performed on carbonate chernozem of loess terrace i.e.on soil of convenient mechanical composition (loam) of crumby structure,stabile structural aggregates and of very suitable water-air regime defined as "regime of a self-regulating character" (Vučić,1964).

Having in view such very favourable physical properties of chernozem and only slight changes during the growing period under wheat (Vučić,Dobrenov, 1967) we supposed that the second crop - silage maize - could be succesfully grown under irrigation with shallower tillage.As the basis in experiments a tillage to 25 cm had been taken and it is suggested for maize on chernozem in regular planting (Drezgić,Marković,1964) with three variants of shallower tillage:to 10,15 and 20 cm.

The results obtained in the first experimental years indicated to the possibility of further tillage reduce hence beside minimum tillage - with discing,the experiment had been extended by sowing without tillage ("zero tillage").

RESEARCH RESULTS AND DISCUSSION

A high uniformity was found in three-year yield average of fresh matter of the first experiment in all variants (Table 1),hence starting from the con-

Tab.1-Silo maize yield of second crop depending of the depth of ploughing (three years average)

Depth of ploughing,cm	Fresh matter,mc/ha
10	489,4
15	487,7
20	497,9
25	483,6
	LSD o,o5 = 45,1 mc/ha

ditions under which maize as second crop has been grown something similar had to be expected from the second experiment too - with reduced tillage to the direct sowing on stubble field. This assumption was confirmed to a certain extent (Table 2) and no significant differences were found in the fresh matter yield between the

Tab.2- Silo maize yield with "minimum" and "zero" tillage (mc/ha)

Depth of ploughing cm	1.year	2.year	3.year	Average
"Zero" tillage	428,6	475,8	365,8	410,7
Discing 8-10 cm	496,3	440,3	356,9	431,2
15	494,8	496,1	341,5	444,1
			LSD 0,05 = 60,6 mc/ha	

variants on an average, though there were some differences between years.

The maize as second crop comes after winter wheat which as a crop of density stand protects soil from compaction of ploughing layer (Vučić, Jocić, 1967) and protects the soil structure. Besides that tillage of 30-35 cm has been used for wheat. After sprinkling, once or twice during vegetation, only slight increase of soil volume weight was found (for 0,09) and only in top 5-6 cm. Therefore the physical condition of the soil was very suitable in all variants (Table 3).

Tab.3- Volume weight (a), total porosity (b) and aeration porosity (c) of soil after sowing of second crop

Depth of soil, cm	Depth of ploughing, cm														
	0			10			15			20			25		
	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c
0-10	1,2	51	19	1,1	55	26	1,1	56	27	1,1	57	28	1,1	57	28
10-20	1,3	49	15	1,3	49	15	1,2	51	18	1,2	57	28	1,2	52	20
20-30	1,2	52	20							1,2	52	21	1,3	49	15

Besides that the maize as second crop has been grown only with irrigation consequently the soil layer from 30-50 cm is moist throughout the vegetation and there was no physical interference in root system development in all experimental variants.

The results in the Table 2 refer to the production with cultivated crop hence the question is whether cultivation could be replaced by herbicides or left out completely having in view the conditions under discussion.

The further investigations showed that the application of herbicides could replace cultivation, however, quite low yields were obtained without weed control (Table 4). The negative effect of weeds on the

Tab.4- Effect of cultivation and herbicide use on the silo maize yield (Rel.ratio)

Depth of ploughing,cm	Cultivated	Non cultivated	
		without herbicide	with herbic.
No tillage	96%	60%	87%
Discing	95%	64%	97%
15	100%	82%	98%

maize plant growing is in question, plants were weak without herbicide use and for about 50% lighter in weight.

Mention must be made that the number of weed plants per m^2 was not in accordance with the above statement (Table 5).

Tab.5- Number of weed plants/m^2 at harvest time

Depth of ploughing,cm	Cultivated	Non cultivated	
		without herbicide	with herbic.
No tillage	4,8	27,9	21,9
Discing	5,7	58,6	26,4
15	2,0	34,8	24,6

However, in sowing without cultivation the soil surface is already under weed stand and their effect on the maize shoots is greater combined with tillage and discing where weed plants grow later and are smaller in growth considerably.

At the end it should be added that the chemical composition of the plants was similar in all experimental combinations, however, the combination without cultivation and partly with discing, has about 1% dry matter less which reflected on the total nutritive value of second crop silo maize.

We came to the conclusion that it is definitely necessary to prepare the seed bed by shallowest tillage or discing for growing silo maize as a second crop on the chernozem under the climatic conditions of Vojvodina (Yugoslavia). The production can be made cheaper and simpler by herbicide use and without cultivation.

The production without tillage offers lower yields of fresh matter and nutritive (oat feed) units, but it is probable that the economy of production could make some corrections.

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THE DEVELOPMENT OF A DOUBLE DIGGING MACHINE

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Abstract

The need for improved cultivation of the subsoil has arisen because of compaction associated with increased traffic on soils and because existing subsoilers achieve only a limited soil loosening effect. Fixed tine subsoilers have a high power requirement and short operating season. Design combinations for comprehensive loosening of the profile and retaining the top soil and subsoil in separate layers are considered. The Wye double digger uses a mouldboard to expose the subsoil and a power driven rotary tiller in the furrow bottom. Power requirement is approximately 180 kWh/ha compared with the 186-429 kWh/ha for fixed tine subsoiling.

Introduction

The adverse effects of modern mechanised crop production have been highlighted in the United Kingdom by the Agricultural Advisory Council (1970) and Soane (1970). In the Netherlands, Ouwerkerk (1969) has found larger pore space values on soils not cultivated by tractors compared with similar soils on mechanised farms. Deleterious effects of compaction have been reported on root growth of crops such as decreased rates of elongation and increases in root diameter, (Eavis and Payne, 1968; Gooderham and Fisher, 1972) and to some extent on yield (Fisher et al 1975). On the other hand yield increases attributable to subsoiling have been variable. Both Russell (1956) and Hull and Webb (1967) have shown small but consistent increases in yield from subsoiling. Improvements in the quality of roots such as sugarbeet have been more easily demonstrated (Czeratzki, 1965). These small responses may in part be due to the limitations of existing subsoiling machines where fissuring and shattering of the subsoil will only be possible if the subsoil is dry. It seems probable that these dry subsoil conditions seldom occur in the United Kingdom and then for only a few days in the year.

Another disadvantage of existing tined subsoilers are the high tractive power requirement necessitating a crawler or four wheel drive type tractor and also preferably a dry operating surface. This further restricts the time when the operation can be successfully carried out. To reduce power requirements, attempts have been made to oscillate the subsoiling tine which, although it may reduce draught requirement by 35% (Hendrick and Buchele, 1963) requires extra energy to produce the oscillations with the net result of a higher overall power requirement. Other ideas to reduce draught requirement include the slant subsoiler (Ede 1974), where fissuring is improved by bending the mass of soil as it flows over the blade rather than a shearing action of the subsoiler blade, or mole plough. Also Spoor (1975) has described the advantage of placing wings on the bottom of the subsoiling tine, or shallow cultivation ahead of the subsoiler to increase the total disturbed area and give better rearrangement and rotation. This will however depend on dry subsoil conditions and on the condition of the surface layer. Despite these developments it is considered that the mechanical comprehensive loosening of subsoil has seldom been achieved. However, the effects of thorough subsoil loosening by hand digging has been investigated (Gooderham, 1976) and the Wye double digging machine has been developed to reproduce the same effects.

Design

From this experimental work conducted at Wye College, it was concluded that the two main machine requirements were (i) to break up the subsoil very thoroughly and (ii) retain the topsoil and subsoil in separate layers. To achieve this, various design combinations were considered, (Fig.1). These were:

(i) double depth mouldboard plough: Double depth mouldboard ploughs have been used in Australia and Russia. Zabashtanskii (1973) refers to deep ploughing Chernozem soils in Russia using ploughs capable of 2 and 3 layer ploughing simultaneously down to 40 and 60cm depth respectively. However, the draught requirement is high and traction a problem at low speeds. Doubt also must remain as to the amount of soil breakdown with a moist subsoil.

(ii) mouldboard plus tines: This type of subsoiling is practised on the heavy clays in the Eastern Counties of England to alleviate plough pans but has a high draught requirement. The extent of the loosening effect would be expected to be critically dependent on soil conditions. Although it is possible that a slant tine subsoiler could increase the amount of fissuring, the power requirement would still be high.

(iii) rotary cultivator plus tines: This form of subsoiling is commercially developed as an "under-buster" for a rotary cultivator. Although rotary tillage of the topsoil reduces the draught requirement, the loosening effect of the tines would again depend on subsoil moisture conditions.

(iv) twin rotor tiller: By mounting one rotor for the topsoil and one for the subsoil it would be possible to produce a controlled comprehensive loosening through the profile. In order to expose the subsoil, the top rotor may need to be driven in reverse which would increase the draught requirement. Despite the high overall power requirement, cultivating, subsoiling and planting would be possible in one pass. Furthermore, unlike the vertical rotating tillage tools such as the Fowler gyrotiller, soil mixing would be kept to a minimum.

(v) mouldboard plus rotor: This combination uses the mouldboard's displacement capability as a means of separating the topsoil and exposing the subsoil to enable separate cultivation of it in situ. By applying rotary tillage to the subsoil only, a reduction in the draught requirement will be possible and the total power requirement of the machine will then be within the capabilities of a medium horsepower 37-56 kW wheeled tractor. Furthermore, rotary tillage would enable loosening of the subsoil to be carried out under moist conditions.

Wye Double Digger

The first version of the double digging machine is based on a single furrow deep digger plough where the beam was lengthened to accommodate the subsoiling rotor. This runs in the furrow bottom exposed on the previous pass with the plough body turning the topsoil onto rotary tilled subsoil (Plate 1). The subsoiling rotor is driven from a bevel reduction gearbox slung underneath the plough frame. This gearbox when fitted with interchangeable spur gears gives a choice of rotor speeds from 120-240 r.p.m. at 540 r.p.m. engine power take-off speed. The rotor has three flanges, supports three pick tines per flange, and is roller chain driven at one end. The linear depth is fixed at 22 cm. below plough depth although it is possible to vary this depth by slackening off the supporting frame and rotating the gearbox extension tube to a fresh position. Pick tines have been used because of their relatively small cutting surface to soil moved which minimises power consumption and risk of blockage under moist conditions.

Power requirement

Preliminary performance tests have been encouraging. A 34 kW tractor equipped with instrumentation for continuous monitoring of engine speed and torque (Wilkes, 1972) was used to collect data when cultivating a silt loam. So that power requirement could be determined the effect of forward speed was examined at rotor speeds of 128, 161, 224 r.p.m. A summary of the results are shown in Table 1 for two forward speeds only.

Table 1. Effect of forward speed and rotor speed on power requirement

Forward speed km/h (m.p.h.)	Tractor engine load kW(hp) Rotor speeds		
	128	161	224
1.85 (1.15)	17.5(23.3)	19.9(26.5)	22.1(29.4)
2.34 (1.46)	19.8(26.4)	22.2(29.5)	23.1(30.9)

It was not possible with the tractor available to operate at higher forward speeds at either the lowest (128) or highest (224) rotor speed. In the first case bite length caused the machine to ride out of work and at the highest rotor speed the tractor had insufficient power.

It is clear from Table 1 that approximately 20 kW are required for working 45 cm deep and 45 cm wide at 2.34 km/h with the double digging machine. This gives a spot working rate of 0.11 ha/h or 180 kWh/ha. In contrast, depending on soil type and moisture content a single subsoiling tine can have a draught ranging from 1816 to 2724 kg. On this basis, operating a tine subsoiler at 3 km/h requires between 26 and 60 kW for working at the same depth. To give a comparable profile disturbance to double digging, tines would need to be spaced at no more than 45 cm. This gives a rate of work of 0.14 ha/h, and a power requirement of between 186-429 kWh/ha. One reason for the higher power requirement is because only about 50% of engine power is available for draught. In future development work with the double digger, the power required for draught and for the rotor on a wider range of soil types will be itemised.

Soil cultivation and crop yield

The effect of double digging on mechanical resistance of silt loam, measured with a cone (diameter 2.0 cm) penetrometer is seen in Fig. 2. Mechanical resistance was halved, and there were only small differences between the various rotor speed/forward speed combinations.

The effect on sugarbeet yield of three contrasting subsoil loosening techniques have been investigated on a silt loam (Table 2). In both 1974 and 1975, fresh weight yield was increased by about 13% when comparing double digging with vibrating and fixed tined subsoiling treatments. The tined subsoiling treatments reduced fresh weights by about 3% when compared with the control.

Table 2. Effect of subsoil loosening on sugarbeet yields 1974-75

		Plough (control)	Double digger	Vibrating subsoiler	Fixed tine subsoiler	LSD (P=0.05)
Depth of working (cm)	1974)	22	32	) 45	) 45	-
	1975)		35	)	)	
Spacing of tines (cm)		-	-	27.5	27.5	-
Yield of fresh) roots (t/ha)	1974	38.3	41.3	37.6	36.6	5.5
	1975	26.2	29.2	25.1	25.9	4.0

Although data is not presented here, increases in water holding capacity, air porosity and reductions in mechanical resistance of subsoil associated with mechanised double digging were found. This confirms results previously obtained by hand-digging (Gooderham, Op.cit). Similar effects associated with the tined subsoiling treatments were smaller.

Effects on subsoil physical conditions of loosening by hand-digging have been detected up to four years after application of treatment (Gooderham and Wilkins, unpublished data). It seems probable therefore that sub-soiling does not need to be carried out annually. Double digging offers a technique for loosening compact subsoil prior to the introduction of direct drilling and may even extend the range of suitable soils. A further possibility, requiring investigation, is the addition and mixing of fertilizers and soil conditioners to subsoil.

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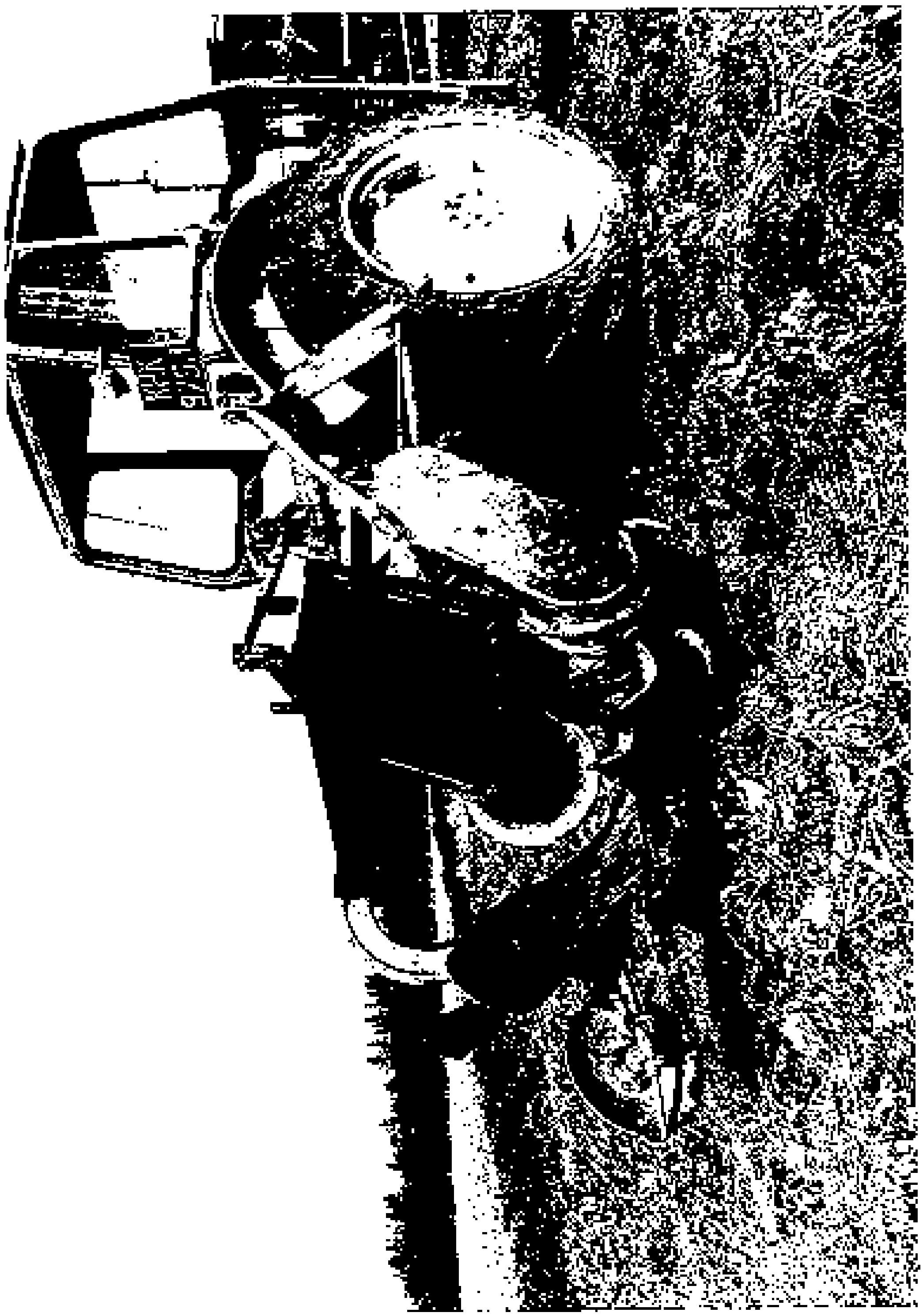


Plate 1.

Fig.1. Design combinations for double digging.

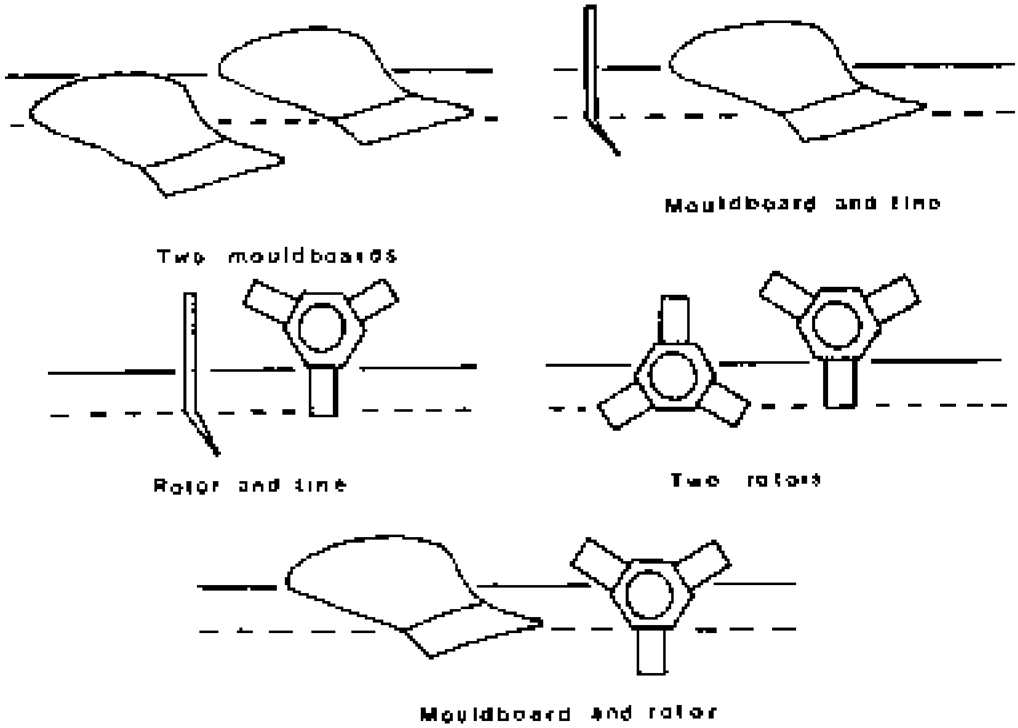
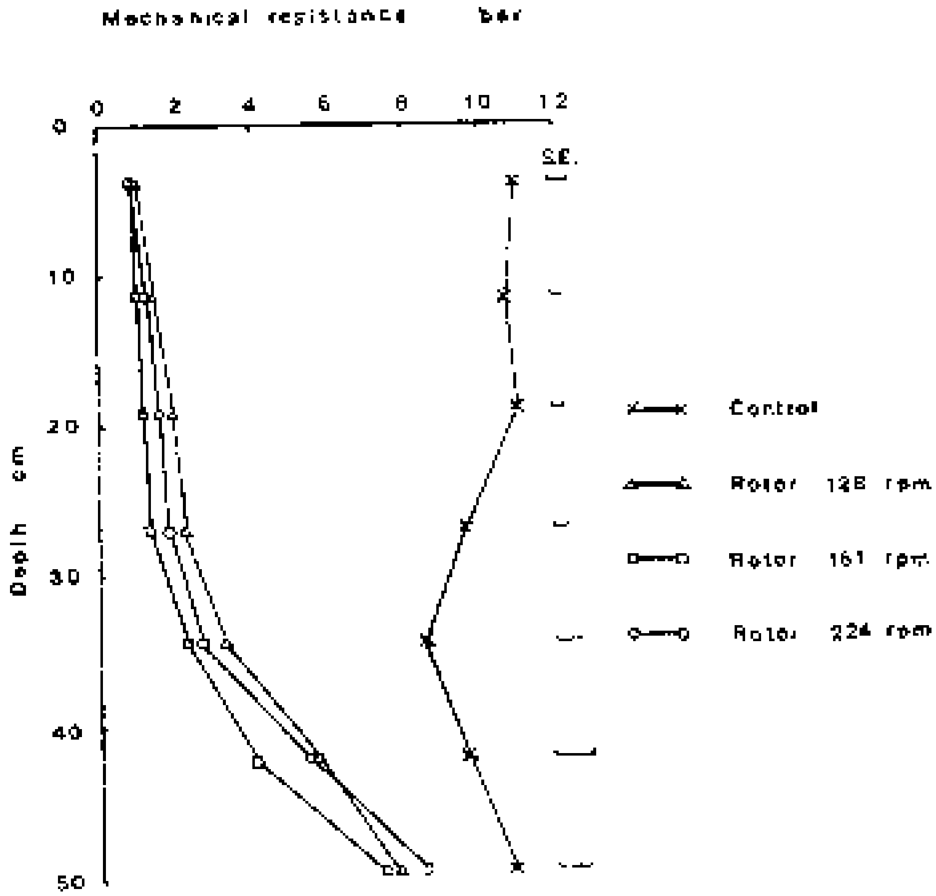


Fig.2. Effect of double digging on soil structure.



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Tillage as a weed control measure in the tropics.

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ABSTRACT

Chemical weed control in the tropics is restricted because of high costs, environmental consequences and lack of education of most of the farmers. Proper tillage operations can reduce weed problems enormously: mouldboard ploughing will at all levels of mechanization surpress the potential annual weed problem and carrying out the deepest tillage operation in the very beginning of the dry season, when soil moisture content is still rather high, followed by repeated operations will result in a high degree of desiccation of perennial weeds. As an inter-row crop cultivation, earthening up with ridgers appeared to be the best control measure; for smaller crops, planting on ridges and tine cultivation with reridging will also give a high degree of control.

Introduction

Tillage and weed control after sowing account for a labour peak on farms all over the world, whether it be tropical or temperate regions. In the latter, with a capital intensive production system, weed control after sowing is mainly carried out in a chemical way. However, the rise in the costs involved and the knowledge of the environmental consequences of the use of chemicals revived interest in an agricultural production with a minimum use of chemicals.

In the past, when chemicals were hardly available, tillage was generally recognized as a major tool to keep weed growth under control. As soon as herbicides were discovered the attention of weed scientists was almost completely absorbed in this field, more or less in the same way as mechanization aspects absorbed the attention of tillage research workers.

Weed research in the tropics was carried out in a rather restricted way: mainly a screening of herbicides from temperate regions to be used in the tropics.

As most of the tropics is occupied by developing countries with a severe lack of hard currency, the rise in the costs of chemicals will restrict strongly on the use of herbicides. The environmental consequences may be more bearable than in most of the temperate countries, because of the absence of industrial pollution and of a historical accumulation. But a much bigger problem in using herbicides in developing tropical countries is the education of the rural population. How can a local farmer know what herbicide to use in what way at what time for a certain crop?

This fact makes it necessary, certainly for the first decades to come and, if the costs of herbicides are not going to fall, perhaps even forever, that research towards the weed control aspects of tillage is intensified and given full attention.

General remarks on tillage as a weed control measure

In weed science, specific groups of weeds have to be distinguished as they need a different approach in controlling them:

1. weeds propagated by seed(mainly annual weeds)
2. weeds propagated by vegetative parts(mainly perennial)

Seeds from weeds require specific conditions concerning depth of burial, water, oxygen, temperature, light intensity and daylength for their germination. With tillage, water, oxygen and temperature can be influenced to a certain extend but more can be done concerning the depth of burial. If for instance mouldboard ploughing is carried out in a proper way using skim coulters, almost the complete top layer, with freshly spread seeds, can be transported to the bottom of the ploughed layer. Although we do not know very much about the survival of seeds in soils at high temperatures, it might be expected that this is less than in temperate regions.

Perennial weeds can be controlled either by exhaustion or desiccation. For exhaustion a non-dormant period will be required so in most cases a fallow growing season will be necessary. For desiccation a dry period is needed which is available in all except the humid tropics.

The above measures are mainly to keep the potential weed population down. Concerning the repressive weed control measures it can be noted that the vegetative crop growth in the tropics is faster than in temperate regions. That is why weed control between planting and crop closure is relatively easier.

To test some of the above assumptions, a number of experiments have been carried out in the savanna of the northern part of Nigeria in 197- and 1975.

The influence of pre-planting tillage operations on weed growth

In the experimentation three levels of mechanization were included in separate experiments:

1. animal power
2. two-wheel(8.5 hp) and small four-wheel(12.5 hp) tractor
3. big four-wheel tractor(65 hp)

With animal power, the following treatments were compared:

I. mouldboard ploughing with additional tine cultivation,
II. mouldboard ploughing only,
III. ridging in untilled soil,
IV. tine cultivation only.

Traditionally all crops are planted on ridges, which are split next season and rebuilt either on the same spot or in the furrow. As the experiment was started on flat soil, treatment III is not a traditional one.

Weed growth 17 days after the tillage operations averaged over two implements, which differed not significantly, and over six replicates is given in table 1.

Seedbed preparation after ploughing is not significantly better than ploughing only, but not ploughing is really very poor concerning weed control.

Table 1. Weed weight(dry matter of areal parts) and tillage depth for the animal powered experiment

Treatment	I	II	III	IV	Lsd $_{.05}$	Lsd $_{.01}$
Depth (cm)	15	15	7.5	5		
Weight(gr/m^2)	3.6	5.0	24.7	29.6	9.7	12.3

The treatments compared at the second mechanization level were:

a) two-wheel tractor :

I. mouldboard ploughing only

II. mouldboard ploughing and rotavating

III. rotavating only

b) four-wheel tractor:

IV. mouldboard ploughing only

V. mouldboard ploughing and disc-harrowing

VI. disc harrowing only.

Weed growth 21 days after tillage averaged over five replicates is shown in table 2.

Table 2. Weed weight(dry matter of areal parts) and tillage depth for the small tractor powered experiment

Treatment	I	II	III	IV	V	VI	Lsd $_{.05}$	Lsd $_{.01}$
Depth(cm)	11.0	11.0	8.5	7.5	7.5	4.5		
Weight(gr/m^2)	100.7	30.4	46.2	44.5	70.5	187.3	61.8	95.5

A Japanese type of plough(treatment I) is controlling weeds not as good as a normal mouldboard plough(tr.IV), however not significantly. Only shallow disc harrowing gives a really poor weed control.

At the highest mechanization level the treatments were:

I. disc ploughing and disc harrowing

II. mouldboard ploughing

III. chisel ploughing

IV. rotavating

V. disc harrowing

Weed growth 21 days after tillage, averaged over 2 replicates is presented in table 3.

Table 3. Weed weight(dry matter of areal parts) and tillage depth for the four-wheel tractor powered experiment

Treatment	I	II	III	IV	V	Lsd $_{.05}$	Lsd $_{.01}$
Depth(cm)	21	22	18	20	8		
Weight(gr/m^2)	53.0	7.4	28.9	45.4	29.4	42.0	69.7

Reversing the soil with a mouldboard plough resulted in a very good control of weeds, while mixing(disc plough and rotavator) was clearly worse but still much better than breaking up the soil only(chisel plough)or a shallow disc operation.

About the control of perennial weeds only preliminary trials have been carried out on the desiccation of Imperata cylindrica and Cyperus rotundus. It appeared to be very difficult to penetrate into the soil deep enough in dry season with normal farm equipment. To be able to follow this line of weed control, this has to be carried out either by heavy(e.g. land clearing) equipment or to carry out the deepest operation immediately after the harvest of an early crop when the soil moisture content is still reasonable high. Once sufficient depth is reached, i.e. the depth of the deepest vegetative parts, one season of about 6 months of drought is sufficient to eradicate the above mentioned weeds. No difference could be seen between disc ploughing, chisel ploughing or rotavating with underbuster.

The influence of inter-row cultivations on weed growth

On a very heavily infested field with mainly Cyperus rotundus and C.esculentus an animal powered experiment has been carried out to study the possibility to grow a crop of maize in spite of this infestation. The treatments in the maize crop planted on the 25th of May were:

I. tine weeding on June 4,15 and 26,
II. tine weeding on June 12 and 26,
III. sweep weeding on the same dates as I,
IV. upridging gradually on the same dates,
V. tine weeding and upridging of the pre-planting ridged crop also on the same three dates.

Weed growth on the 9 of July averaged over four replicates is shown in table 4.

Table 4. Weed weight(dry matter of areal parts) of some inter-row cultivations

Treatment	I	II	III	IV	V	Lsd $_{.05}$	Lsd $_{.01}$
Weight(gr/m^2)	129.6	174.9	250.0	54.6	81.5	63.2	91.5

From these results it can be seen that cutting weeds with a sweep without throwing up soil into the row is a poor weed control measure. Secondly it is clear that timely and frequent cultivations are essential to get the best results. Thirdly earthening up by ridgers is a very good system to control weeds even in the row.

General conclusions

Mouldboard ploughing seems to be necessary in controlling weeds at all mechanization levels. But as this requires rather much labour, the traditional way of primary cultivations by ridge splitting, which reverses also much of the top soil might be a very good alternative.

Inter-row cultivations, carried out timely and with the right implements can keep weed growth under control until crop closure. The system of earthening up can be applied to tall growing crops like maize, millet, sorghum and

cotton and the tine weeding with reridging or tine weeding only for lower crops like groundnut and cowpea.
A good sequence of tillage operations, pre- and postplanting, can reduce weed problems enormously.

Fig.1:Mouldboard ploughing using animal power.

Fig.9:
Tine weeding straddling
the row to overcome
problems of
non-parallel planting

Fig. 3:
With earthering up
and with tine weeding
and ridging soil
is thrown into the
plant row.

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SOIL TANK AND FIELD STUDIES OF COMPACTION UNDER WHEELS

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ABSTRACT

The measurement of bulk density, cone resistance, vane shear strength, air entry rate and plate sinkage is described in relation to studies on the distribution of compaction under tractor wheels with and without the addition of cage wheels. The advantages of using a number of soil physical properties for this purpose, particularly with the aid of a soil test trailer are discussed. Care is needed in selecting a reference datum level for subsurface measurements. A limited number of tests were made on the effect of adding a cage wheel to a standard tyre and of using a cage wheel instead of a tyre on 30 cm of loose sandy loam overlying compacted soil of the same texture to simulate a cultivated seedbed. Adding a cage wheel reduced the maximum intensity of compaction but did not reduce the total compactive response. These effects may be modified by changes in design which transfer a greater proportion of the axle load to the cage wheel.

INTRODUCTION

Our studies are concerned with the incidence, importance and reduction of soil compaction under wheels in commercial crop production. Of immediate interest are the selection and measurement of relevant soil properties and the techniques for comparing the results obtained under different types of wheels. Later the studies will be extended to include the inter-relationships between soil type, machinery management systems and climatic conditions. An integrated programme using full scale vehicles in a soil tank (15 m x 2 m x 0.5 m) and in the field is underway and this paper considers some preliminary results using quantitative techniques for comparing compaction under different wheel systems.

SELECTION OF SOIL PROPERTIES

Apart from an increase in bulk density, compaction results in changes in many other physical properties which may be of more practical importance. Soil properties selected for measurement should preferably show high sensitivity i.e. a large change in value in relation to the errors of measurement and be capable of rapid and convenient measurement with a high degree of spatial resolution. The results should be of relevance in interpreting soil responses with respect to plant growth and/or machinery operation. A property related to root growth (e.g. in some soils cone resistance) may be unsuited for the assessment of soil strength near the surface which is of particular importance in assessing direct drill performance in zero-tillage experiments and for which vane shear strength would be more appropriate. Our approach is therefore to measure as many relevant soil physical properties as circumstances permit. The tests receiving most attention here are as follows:

Dry bulk density, total porosity, air-filled porosity. The gamma-ray transmission method with equipment similar to that described by Soane et al. (1971) is used but with 22 cm spacing between probes. Readings are obtained at 3 cm increments to 39 cm depth with the probes inserted by hand or hydraulically. The method, though much quicker than the use of core sampling, is still slower than the methods used for soil strength. Disturbed samples are taken by a screw or tube auger for water content measurement by oven drying.

Cone resistance. A 12.9 mm dia. 30° cone is inserted at 30 mm/s either by hand or by electrical drive. Readings taken at 3 cm increments to 39 cm depth using 9 positions 10 cm apart across wheel track. Magnetic tape recording is used on the soil test trailer. The method is rapid, convenient and shows a high degree of spatial resolution and sensitivity.

Vane shear strength. A 19 mm dia., 28 mm high, four bladed vane is inserted and rotated by hand, maximum shear strength is indicated by a captive needle against a calibrated dial. In these tests, readings were taken at 18, 27 and 36 cm depth. The method is very quick and simple to operate and has a high degree of spatial resolution and sensitivity.

Air entry rate. A manually or hydraulically-inserted permeameter (60 mm dia.) is used to measure the flow of air at a pressure of 25 cm water at the surface or sub-surface respectively. Readings are taken in the midline of the wheel track. The results will be related primarily to the number of large pores present.

Plate sinkage. A 118 mm dia. plate is lowered electrically at 30 mm/s until the resistance reaches 90 kN/m^2 which corresponds approximately to the inflation pressure of many tractor rear tyres. Load and sinkage are recorded on magnetic tape and the results expressed in terms of sinkage (mm) or the slope of the load/sinkage relationship (kN/mm). While the method gives no information on the distribution of sub-surface soil responses it indicates the relative bearing capacity of different soils before and after the passage of wheels, readings being taken in the midline of the wheel track.

In the soil tank and in some circumstances in the field, these measurements are undertaken from a soil test trailer having a wheel track of 2.8 m (Soane, 1975). This has the advantage of avoiding any foot traffic over the test soil area, of utilising electrical and hydraulic power supplies from the towing vehicle to aid the insertion of the test equipment and may increase the output of test results per man-day.

EXAMPLES OF SOIL RESPONSES

An example of the change in bulk density with the passage of a tractor wheel over cultivated sandy loam in the field is shown in Fig. 1. The compactive change was marked throughout the cultivated layer. With the gamma-ray transmission method it is easy to take readings at small increments of depth permitting detailed information to be gained on the changes of bulk density in the profile which would be difficult to achieve by other methods.

For a sandy loam soil in the soil tank (30 cm depth loose soil overlying compacted soil) the changes in cone resistance, vane shear strength, air entry rate and plate sinkage before and after the passage of a medium power tractor with a cage wheel fitted are shown in Table 1. The increase in vane shear strength was significant ($P = 0.05$) for both cage wheel and tyre at all three depths whereas for cone resistance the increases were not significant at 18 cm depth but significant at 27 cm depth. At 36 cm depth the increase in cone resistance was significant below the tyre but not below the cage wheel. Plate sinkage decreased significantly below the cage wheel and tyre, the greater difference being below the tyre. The decrease in air entry rate was significant under the cage wheel at all depths but only at 18 cm below the tyre. The relative changes in these properties do not follow a similar pattern in all cases and further work will be required to confirm the validy of the differences and assess their importance.

Statistical comparisons. Where the test result can be expressed as a single figure, e.g. plate sinkage, comparisons are straightforward. However, complications arise in comparing results of properties which

TABLE I

EXAMPLES OF CHANGES IN SOIL PROPERTIES AS A RESULT OF THE PASSAGE OF A MEDIUM POWER TRACTOR WHEEL FITTED WITH A CAGE WHEEL

Property	Depth cm	Value before passage	Value after passage (midline) Cage	Value after passage (midline) Tyre	S.E.	C.V. %	Relative value after passage Cage Initial = 100	Relative value after passage Tyre
		mean of 10 positions						
Vane shear strength (kN/m^2)	18 27 36	12 27 49	29 47 73	29 58 77	2.4 4.4 6.7	33 31 32	240 170 150	240 220 160
Air entry rate (l/min)	18 27 36	13.5 5.7 3.3	7.5 3.5 1.7	9.1 4.0 3.1	0.8 0.6 0.3	25 41 36	55 61 51	67 70 94
Plate sinkage (mm)	0	100	43	24	6.8	38	43	24
Cone resistance (kN/m^2)	18 27 36	40 70 250	70 250 330	50 290 510	16 24 32	49 20 14	170 360 130	130 410 200

vary both horizontally and vertically within the soil below the wheel track. The simplest approach is to confine attention to the soil below the midline of the wheel (Fig.1 and Table I) and to compare separately the results obtained at different depths. This approach may be extended to results obtained on a two-dimensional grid. The use of statistical techniques for individual comparison of a considerable number of grid points may, however, merely regenerate a complex pattern which is itself difficult to interpret. A simplification can be made by analysing the statistical significance of the difference in the value obtained at each point of measurement before and after the passage of the wheel and then obtaining the sum ($\sum x$), mean ($\bar{x}$) and standard deviation (σ) of those differences which reached a selected level of significance, in our case $P = 0.10$. These parameters may then be used to compare the effects resulting from different wheel systems (see later).

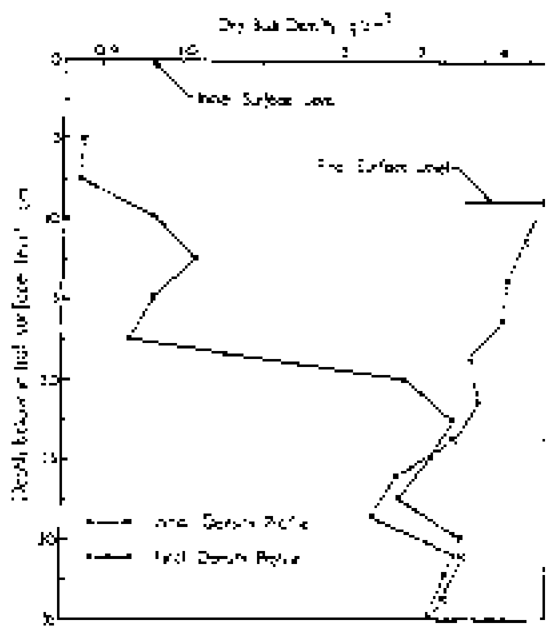


Fig.1. Example of use of initial surface level as datum in study of compaction under tractor rear wheel (MF 135, 1830 kg, 35 dW) on passing over cultivated soil

Depth transformations. Comparisons of results of tests made on soil at different states of compaction are complicated by the problem of selecting a common datum level from which to measure depths within the soil profile. In general, use of the soil surface as a datum is not satisfactory when the changes in bulk density are extreme, or where soils shrink or swell with changing moisture conditions, but it is possible in some cases to use the surface in either the dense or the loose state and the latter technique is illustrated in Fig.1. The matching in bulk density values within the subsoil agree within 1 cm in depth, in spite of a 9 cm change in level at the surface as the result of the passage of a tractor wheel. Another technique is to apply to the depth scale a progressive correction, the magnitude of which is based on the differences between the initial and the final bulk density values for successive depth increments (Pidgeon and Soane, 1976). This correction has been employed for measurements of bulk density made over a period of eight years in a zero-tillage experiment, the final bulk density profile being used as the reference state. At the start of the period an upward displacement of data points by 3 cm was required for readings at 33 cm depth (Fig.2). Changes nearer the surface or later in the sequence of measurements were slight.

<u>Data transformations.</u> Results of bulk density or porosity measurements may have little interpretive value unless they are expressed as a dimensionless ratio, such as 'degree of compactness' (Håkansson 1973) or 'relative compaction' (British Standard Institution 1975), by which the value is related to that in a reference packing state obtained in a standard laboratory compaction test. Bulk density results obtained after different periods of zero-tillage for continuous barley have been converted to the relative compaction basis (Fig.2) and these show that in this experiment the cumulative compaction from wheel traffic results in a progressive increase in relative compaction until a value of about 0.9 is reached (Pidgeon and Soane, 1976).

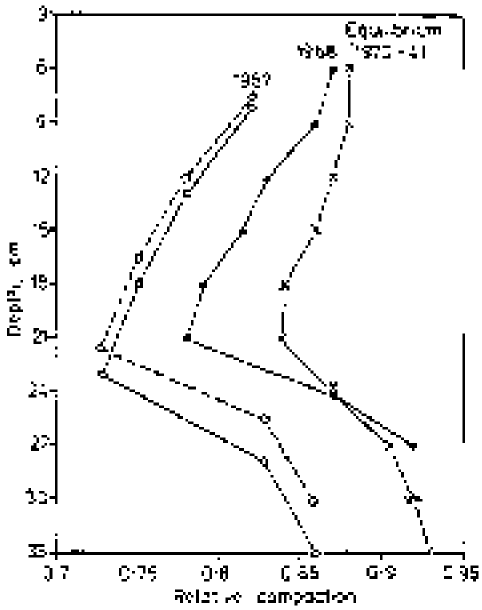
SOME PRACTICAL ASPECTS OF COMPACTION RESEARCH

It is of interest to explore techniques which could achieve a reduction or a redistribution of soil compaction under wheels within the constraints of commercial operations.

<u>Reduction in wheel traffic</u>. From numerous tests in the field we know that a considerable amount of compaction occurs during wheel traffic over seedbeds (Fig.1) and at cereal harvest (Fig.3), and the changes in soil properties occurring during these operations appear to have a dominant effect on soil conditions throughout the year (Soane and Pidgeon, 1975). Cereal farmers now have the option of reducing the amount of wheel traffic during the preparation of a seedbed by the adoption of techniques for reduced or zero-tillage or by linking traditional implements together (Patterson, 1975).

<u>Redistribution of compaction.</u> The possible options for obtaining a redistribution of compaction include spreading the soil responses more widely and uniformly or, alternatively, concentrating the effect into narrower bands. The possibility also exists of moving the zone of maximum compaction to greater or lesser depths. Thus the effects of variation in the dimensions, numbers, type and arrangement of wheels and the inflation pressure of tyres on the nature of the compaction pattern need to be examined. A more dramatic effect is likely to result from the partial or total restriction of wheel traffic to pre-determined locations.

We have investigated in the soil tank the changes in distribution of soil compaction under the wheels of medium size, lightly ballasted tractors (MF 165, 2730 kg, 46 kW; IH 990, 2640 kg, 43 kW) when cage wheels and normal wheels have been used in various ways under zero-slip conditions. The sandy loam soil, estimated to be at 5-10 bar water tension, was loose to 30 cm depth and compacted to a cone resistance of about 70 bar below. Fig.4 (a-f) illustrates the results obtained for cone resistance measurements. The addition of a commercial cage wheel



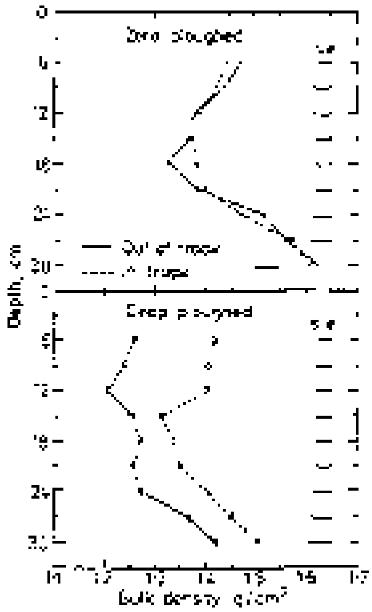


Fig.2 Changes in relative compaction due to wheel traffic during an eight year period of zero-tillage for barley. The dashed line shows data for 1967 plotted at corrected depths equivalent to those of the 1970–74 data

Fig.3 The variation of bulk density in and out of the wheel track of a combine harvester in relation to the tillage method used for growing continuous barley for six years

(134 cm dia., 38 cm width) to the rear wheel (11–36 tyre) of the MF 165 tractor resulted in a markedly wider distribution of compaction and a reduction in maximum intensity (compare Fig.4(b) with (a)). The sums of the compactive effects within the area in which the differences were significant (Σ x) were similar for both tests. The mean increase in cone resistance ($\bar{x}$) was 4.7 bar for the tyre alone but only 2.2 bar for the tyre plus cage wheel. The distribution of compaction under the tyre plus cage wheel was further changed by reducing the inflation pressure of the tyre from 80 kN/m^2 to 40 kN/m^2. Fig.4(d) shows the increase in the cone resistance under the cage wheel resulting from the reduction in tyre inflation pressure, a 60% increase in the sum of the compaction effect (Σ x) being obtained although there was no change in the mean level of compaction. It seems probable that the redistribution of compaction achieved by fitting cage wheels, if thought desirable, would be obtained more effectively by using larger diameter cage wheels than are commonly employed though transferring a greater proportion of the axle load to the cage wheel might require a strengthening of the cage wheel, its fitting mechanism and possible the tractor back axle.

An experimental cage wheel (140 cm diameter, 38 cm width) was used as a substitute for the tractor rear wheel (compare Fig.4(f) and (e)). The sum of compaction effect was increased by 87% though σ decreased from 1.7 to 1.0 bar, the response being spread out over a much wider band. There was little difference in the average values ($\bar{x}_e$ 2.7 bar, $\bar{x}_f$ = 2.9 bar).

When a tyre with normal inflation pressure was run over the wheel track for a second time the additional compaction, Fig.4(c), was confined to a band somewhat above the zone of maximum compaction which occurred during the first pass, an increase of 37% in Σx being recorded. This tendency for the zone of maximum compaction to approach the surface with repetitive passage of wheels has also been found in the field. The compaction effects of the passage of a combine harvester wheel also depended on the occurrence of previous wheel traffic (Fig.3). Soil which has been deep ploughed followed by 100% coverage of wheels during seedbed operations was still in a readily compactable state at harvest whereas soil which had remained uncultivated for six years with barley grown by direct drilling had sufficient strength to resist further compaction at harvest.

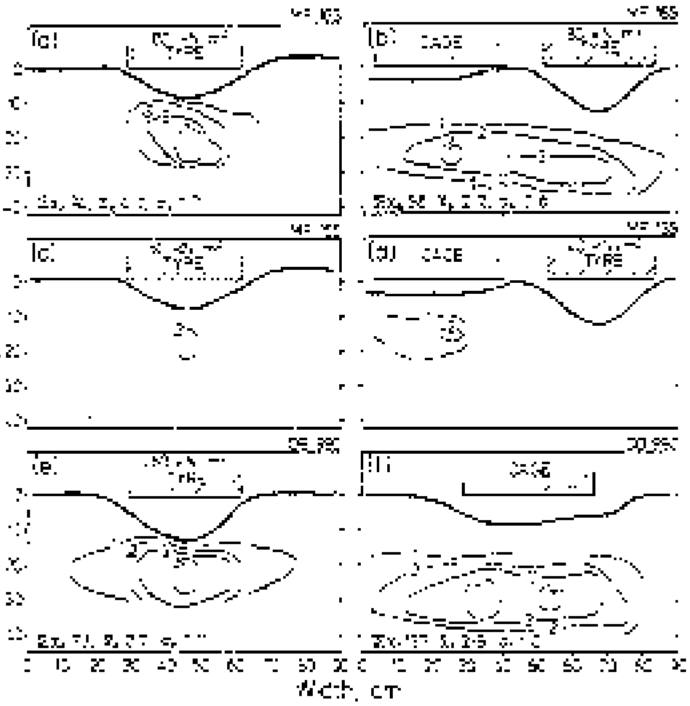


Fig.4 The distribution of increases in cone resistance (bar = $10^2 \times kN/m^2$) resulting from the passage of a tyre (a and e), a tyre plus cage wheel (b), and a cage wheel alone (f). Diagram (c) shows the additional effect from a second pass of the tyre while (d) indicates the additional effect resulting from the use of 40 kN/m^2 inflation pressure instead of 80 kN/m^2 for the tyre when used with a cage wheel

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