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VOLUME 2

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SECTION 4

PERFORMANCE OF TILLAGE IMPLEMENTS

TILLAGE TOOL INFLUENCES ON INCORPORATED WHEAT RESIDUES

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ABSTRACT

Depth and uniformity of incorporated crop residues can have significantly different effects in various tillage systems. Incorporated residue and dry bulk density measured in 20 mm increments showed distinct influences of primary tillage on burial patterns. Less than 45% of wheat residue was buried above 0.1 m with a moldboard plow, while a chisel and a sweep buried 60 and 80%, respectively, of the residue above 0.05 m. Joint patterns of dry bulk density and incorporated residue indicated moldboard plow penetration ranging from 0.15 to 0.34 m in 20 measured sites. Compaction during secondary tillage could generally be determined. Patterns of these two variables after chisel or sweep tillage distinguished maximum primary-tillage depth but did not separate it from compaction during secondary tillage.

INTRODUCTION

Placement of crop residues has long been important in tillage systems. The primary objective in older systems was deep incorporation, but the many new conservation tillage systems have collectively changed expected benefits and detriments from specific surface and buried placements of crop residue (Oschwald, 1978; Cannell, 1984; Allmaras et al., 1988). These objectives may include controls of heat-water-air flow, control of soil erosion, management of microbial effects in nutrient cycles, control of plant rooting, and avoidance of root diseases and phytotoxicity. To evaluate the effects of tillage on these processes, it is necessary to measure the surface and buried positions of crop residue, as well as spatial variability and persistence (decomposition).

Measured aerial distribution of crop residue on the surface has been used efficiently to evaluate the effects of residue (Voorhees et al., 1981). Although there are generalizations about how tillage implements affect the position of buried residues (Greb et al., 1974; Christian and Miller, 1986), it is only recently that an efficient method was available to measure the distribution of crop residue in the buried position (Allmaras et al., 1988). Measured soil properties precisely associated with the measured characteristics of the surface and buried residue has afforded much more accurate interpretations about soil environment within small increments of soil depth.

Changes of conservation tillage systems in the dryland agriculture of the Pacific Northwest may markedly affect surface and buried positions of crop residue (Wilkins et al., 1985). Our measurements were made in a subarea in which rainfall is sufficient to support alternating winter wheat (Triticum aestivum L.)/peas (Pisium sativium L.) in fields adjacent to winter wheat/summer fallow. Prevailing soils in this subarea are Ritzville, Walla Walla, Athena, and Palouse series, which are all Mollisols. In the traditional tillage system for wheat/pea, moldboard plows (0.41 to 0.46 m cut per base share with high clearance) are used after wheat harvest to bury residues ranging from 7 to 10 ton/ha (Allmaras et al., 1985). Stubble is usually chopped before primary tillage and burning is practiced occasionally after a disking operation to reduce crop residue before primary tillage. Other tools of primary tillage (disk, chisel, sweep) are being tested since the new seeders have greater tolerance to surface residues. Numerous passes of secondary tillage with spring-tooth cultivators and harrows are made to apply soil-active herbicides and to create a smooth surface prior to planting peas. Following pea harvest the prevailing primary tillage is chisel plowing (moldboard plows are used sometimes) with spring tooth cultivators and harrows for secondary tillage.

In a winter wheat/summerfallow sequence a moldboard plow is often used for primary tillage in zones with higher precipitation, but in zones with lower rainfall chisel plows, disks, or sweeps are used and frequently moldboarding has not been used for up to 20 years. As many as seven secondary tillages may then be performed with disks, chisel plows (shallow setting), sweeps, spring tooth cultivators, harrows, and/or rod weeders during the summerfallow phase.

Our purpose is to measure the distribution of buried wheat residue in wheat/pea or wheat/fallow systems and to show the effect of primary tillage implement on buried position of wheat residues.

METHODS AND MATERIALS

Twenty farm fields were sampled during 1982 to 1984 to measure the dry bulk density and distribution of incorporated crop residue (coarse organic matter, COM) after wheat residues were moldboard plowed and sufficient secondary tillage performed to plant peas or nearly complete the summerfallow phase. In three additional fields a sweep was used for primary tillage; a chisel plow was used in an additional field.

In each field duplicate or triplicate composites were taken, each composite consisting of at least eight soil cores taken randomly from an area at least 10^3 m^2. A single core for the depth increment of 0 to 0.6 m consisted of 20 mm increments, each with a 19-mm diameter taken with a special sampler that was designed to take a maximum core length of 0.3 m (Allmaras et al., 1988). Each 0.3-m core was transferred to a cutting guide for sectioning into 20 mm increments. After air drying and weighing the sample to determine dry bulk density, the incorporated crop residue was gently separated from the sample (a composite of at least eight cores each 20 mm long), and COM determined by a carbon conservation algorithm after total carbon analysis of the soil and material (incorporated residue plus contaminant soil) separated from the soil (Allmaras et al., 1988). A sieve with 0.5 mm openings was used to guide the separation of incorporated crop residue. A range of 8 to 12 soil cores per composite provided a sample large enough for precise estimates of dry bulk density and COM (coefficients of variability of 5 and 20%, respectively) but also small enough to avoid subsampling for the COM analysis. After the COM analysis was completed, subsamples of the soil from which the incorporated crop residue had been separated were used for additional analyses such as soil pH (Pikul and Allmaras, 1985) and primary inoculum for root disease of peas and wheat (Wilkins et al., 1985).

RESULTS AND DISCUSSIONS

Depth distributions of dry bulk density and incorporated residue shown in Fig. 1, 2, and 3 are typical of those observed from use of the moldboard plow, sweep, and chisel, respectively, after wheat harvest. The standard errors given are means based upon disagreement between duplicate observations each from a composite of at least eight cores each 20 mm long and 19 mm in diameter.

Farm tractors of 30 kW size and associated machinery were used for dryland wheat at site 1 (Fig. 1), whereas farm tractors of 80 kW size and larger were used for supplementary irrigated wheat at site 18 (Fig. 1). Depth of crop residue incorporation at these sites was nearly equal to the mean curve (from 20 sites) shown in Fig. 4. Cumulative relative COM is a parameter normalized to a maximum value of unity using the total COM observed in the upper 0.3 m of the soil profile. A peak concentration of COM greater than 8 g/kg as in site 18 was observed at

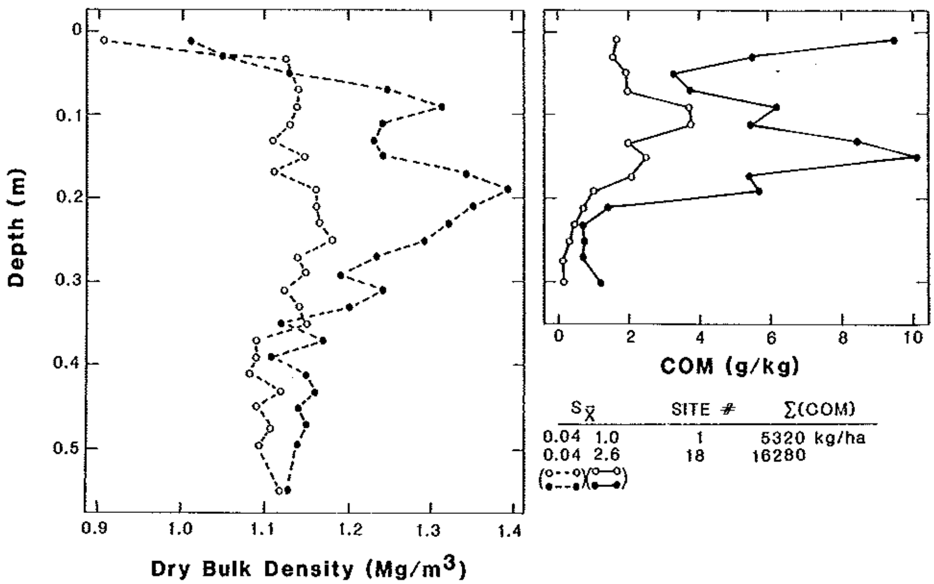

Fig. 1. Typical profiles of dry bulk density and incorporated crop residue (COM) produced by moldboard plowing after wheat harvest.

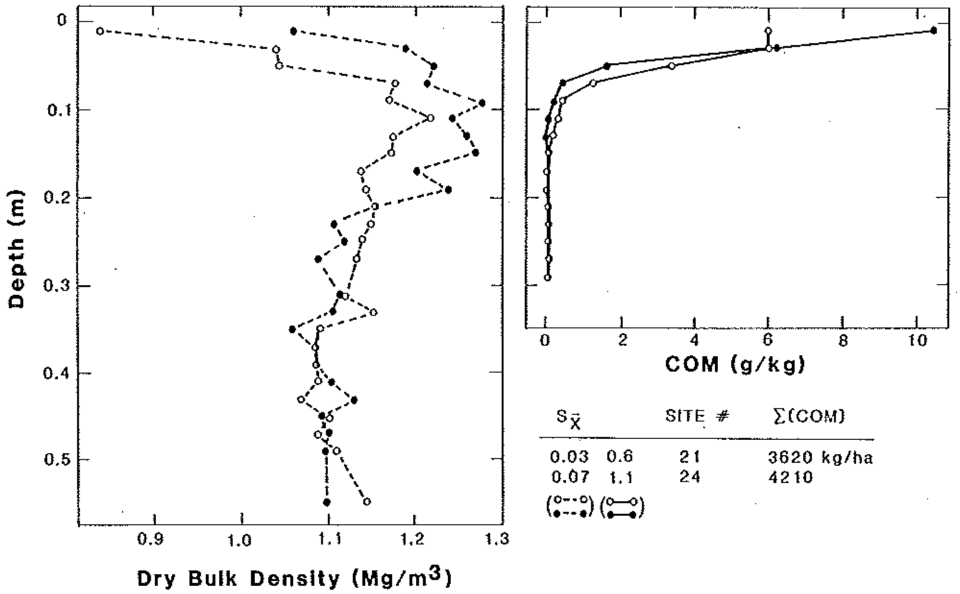

Fig. 2. Typical profiles of dry bulk density and incorporated crop residues (COM) produced by sweep tillage after wheat harvest.

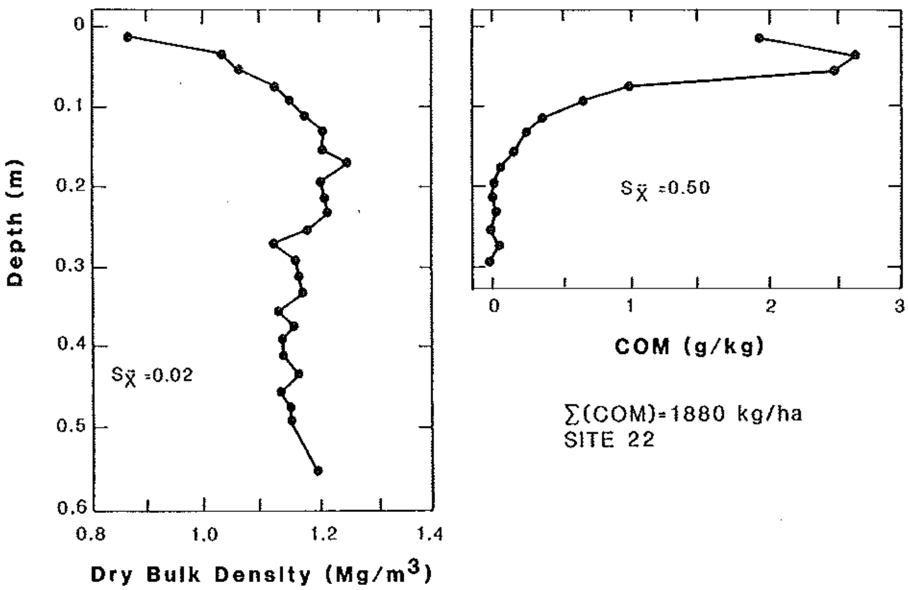

Fig. 3. A profile of dry bulk density and incorporated crop residue (COM) produced by chiseling after wheat harvest.

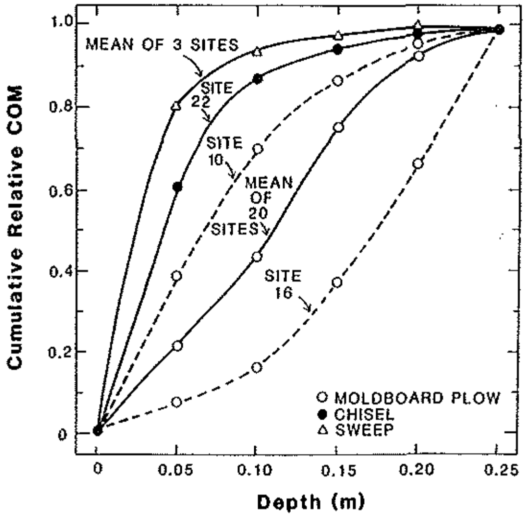

Fig. 4. Depth of incorporated residue as affected by three types of primary tillage.

two sites; a peak concentration greater than 4 g/kg was observed at six sites; and a peak concentration less than 2 g/kg was observed at three sites. The peak concentration of COM at both sites (Fig. 1) located at or below 0.1 m was typical of 16 sites. At six sites the peak concentration of COM occurred at 0.15m or deeper. The three curves of cumulative relative COM for the moldboard plow (Fig. 4) show the mean distribution with depth, and the shallowest (site 10) or deepest incorporation (site 16).

The small peak of dry bulk density (Fig. 1) at 0.25 and 0.31 m at sites 1 and 18, respectively, below the depth of incorporated residue are indicative of the method used to determine maximum penetration of the moldboard plow. This depth varied from 0.15 to 0.34 m with a mean of 0.23 m. A peak dry bulk density at 0.19 m in site 18 (Fig. 1) was produced by traffic during secondary tillage; generally but not always a separation of dry bulk density peaks identified maximum penetration of compaction during secondary tillage and planting operations. There is another secondary compaction zone at 0.09 m at site 18.

Patterns of incorporated residue in sweep tillage (Fig. 2) were nearly identical for sites 21 and 24. A peak concentration of COM occurred in the shallowest sampled depth of 0 to 0.02 m, and 80% of the residue was buried above 0.05 m. Yet, after numerous secondary tillages associated with pea planting (site 21) and with summerfallow (site 24), the estimated surface cover with wheat residue was less than 10%. The dry bulk density curves (Fig. 2) suggest maximum sweep penetration of 0.13 m at site 21 and 0.19 m at site 24, and no distinct separation of compaction zones produced by primary _versus_ secondary tillage. Wheat residue burial with the chisel tillage (Fig. 3) was deeper than with sweep tillage, but yet 60% of the residue was in the upper 0.05 m zone (Fig. 4). There was 3680 kg/ha of wheat residue on the surface, which is partially explained by less secondary tillage than at site 24 during summerfallow. Dry bulk density and COM patterns suggest a maximum chisel tillage depth of 0.2 m.

CONCLUSIONS

The tillage tools tested provide clear differences of wheat-residue incorporation. More measurements are needed to generalize over other types of residue such as corn (Zea mays L.) and soybean (Glycine max L.). Further use of the method for dry bulk density profiles can infer differences of tool action and ultimately rational for farmer preference. Random error of the measured COM and visual observation suggest large variation of concentration within a 20 mm layer, a variation which could have significant effects on soil ecology. Such variations are being studied without composite cores.

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A SUBSOILER WITH PRESSURIZED SEWAGE SLUDGE INJECTION

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ABSTRACT

Sewage sludge contains little potassium but a great deal of nitrogen and phosphoric acid, and it is highly effective as a fertilizer. This research was conducted to determine a method of introducing sewage into the soil under pressure from the tip of a subsoiler chisel. The process would provide plants with fertilizer, improve aeration and soften the soil by liquid static pressure. We designed two different type subsoilers; drawn subsoiler and rotary subsoiler. The method could reduce the power required for performing work below that of the method in which the sludge is permitted to flow downward under gravity into the slitted path created by the tool as done presently by slurry injectors. With the drawn subsoiler, the decrease of power caused by draft reduction was considerably larger than the increase of power required for injecting the sludge itself. With the rotary subsoiler, the power requirements for the system were reduced by as much as 50 percent at the range of a large velocity ratio by injecting liquid sludge under pressure into the soil.

INTRODUCTION

Previous publications (Araya et al., 1981, 1982(a), 1982(b)) showed that the draft and the power required for subsoiling could be reduced when water, air or water-dissolved air was introduced into the soil under pressure from the tip of the subsoiler chisel. The fluid broke down the soil structure in front of the subsoiler, permitting the subsoiler to operate in looser soil conditions. This paper discusses a method to reduce the draft and power needed to operate a subsoiler when sewage sludge is introduced under pressure into the soil layer being loosened. Since sewage sludge is viscous and has a higher resistance to permeability than air or water, the failure produced by the injection of sludge into the soil is larger and a larger draft reduction can be expected.

SEWAGE SLUDGE

Fig.1 shows a flow chart of the typical sewage treatment in the activated sludge system. The frash sludge from the primary sedimentation tank and the excess sludge from the final sedimentation tank are thickened by gravity in the thickener tank. After this, the sludge is digested in the digestion tank for about 30 days, at 28 to 38°C, in which anaerobic processes occur

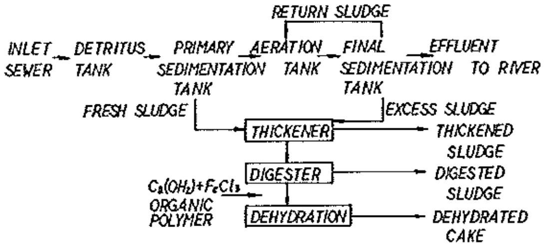

Fig. 1 Typical activated sludge system.

and the complex organic matter is broken down. The sludge used for injection by the subsoiler was taken from the digester and was not dehydrated. The moisture content of this sludge varied with the load at the sewage treatment station (Bolton, 1971). The moisture content of specimens taken from the digester is varied from 98% to 93%.

METHODS

DRAWN SUBSOILER With the subsoiler, the sewage sludge injection studies were carried out on an indoor test field. The sludge was pumped into the delivery system from the sewage sludge tank. A control valve behind the electromagnetic flow meter released a specified flow rate of sludge through the high pressure rubber hose to the nozzle port of the subsoiler. Operational depth of the chisel was 30 cm. As the sewage sludge was introduced under pressure into the soil layer through the nozzle port of the subsoiler, a reaction of the resistance of the flow of sludge through the soil produced a pressure on the nozzle port. This pressure was measured by a pressure transducer on the subsoiler standard. The experimental subsoiler with an elongated chisel used in this study is shown in Fig. 2. The nozzle port was directed upward and its diameter was 14.5 mm.

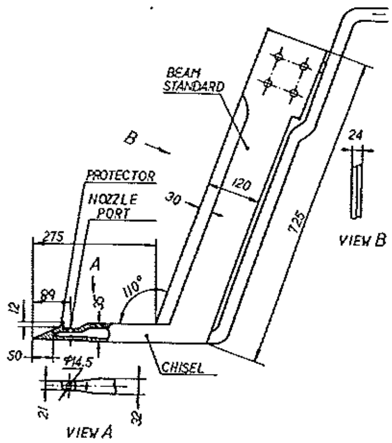

Fig.2 Experimental drawn subsoiler.

ROTARY SUBSOILER An experimental powered rotary subsoiler was designed and constructed (Fig.3). Hendrick (1979) described a rotary subsoiler concept; his subsoiler was similar to the one shown in Fig.3. He showed that it was more efficient to use the rotary subsoiler than to pull a subsoiler with the drawbar. Before equipping this subsoiler with sludge injection apparatus, it was necessary to establish the functional performance requirements. Therefore, test were conducted in the laboratory in a moveable soil bin to determine subsoiler performance with and without sludge injection. Only one blade of the subsoiler was used for tests in the soil bin (Fig.4). The rotary subsoiler radius was 0.5 m, and the blade was set to operate at a depth of 30 cm. The blade was driven hydraulically through a rotation range of 2.27 rad. The speed of rotation was changed through the use of an adjustable hydraulic flow control valve. The torque required to turn the subsoiler blade was measured with strain gages attached to each side of the blade. The rotation of the blade was measured by use of rotary transducer that produced a pulse for every 0.17 rad. of rotation.

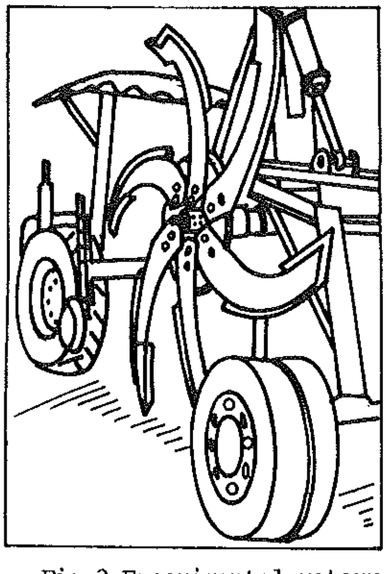
Fig.3 Experimental rotary subsoiler.

RESULTS AND DISCUSSION

DRAWN SUBSOILER Fig.5 shows a displacement and stress field analyzed by FEM for a subsoiler mevement with injected sewage sludge. If the slip line induced by movement of the subsoiler standard is not above the slip line induced by the injected sewage sludge, a larger draft reduction can be expected because a larger volume of soil is broken down. Consequently the nozzle port should be separate from the subsoiler standard, i.e. the chisel should be as long as strength permits, and the nozzle port should be at the tip of the chisel.

Fig.6 shows a sample oscillogram from an experimental test run. In this case, when sewage sludge was injected continuously at a rate of 320 g/s and the operating speed was 26 cm/s, a pressure of 80 kPa was produced at the nozzle port. A base draft of 750 daN was measured when no sludge was injected. Draft was reduced to 450 daN by injection of sludge containing 93 % moisture. The pressure produced at the nozzle port is about 0.1 MPa, which was not extremely high. The draft reduction was affected by the operating speed, the flow rate of injected sludge and the base draft as measured when no sludge was injected. Fig.7 shows this relation for 26 cm/s operating speed. When the flow rate of injected sludge was low, such as 160 g/s, and the operating speed was extremely slow, such as 1.6 cm/s, the sludge had little disruptive effect on the soil with most of the sludge flowing out to the subsoiler path along the surface of subsoiler. In cases when a lubricating effect on the subsoiler by sludge occurred, little draft reduction was observed. Schafer et al. (1975, 1977, 1979) reported that the draft of plows could be reduced by lubricating the surface of plows. But since in the case of the subsoiler, the surface area in contact with the soil is comparatively small, the lubricating effect for the draft reduction is not significant. A stable draft reduction could be observed when the operating speeds increased from 6 to 26 cm/s. The minimum flow rate of injected sludge required for a reduction of draft was approximately 6 g/s for each centimeter of movement of the subsoiler. Fig.8 shows across section of the subsoiler path. A V-shaped breakdown of the soil layer containing the sludge was observed. There was also a great deal of sludge on the chisel path at the center of V.

A benefit of sludge injection in reducing the total power required is

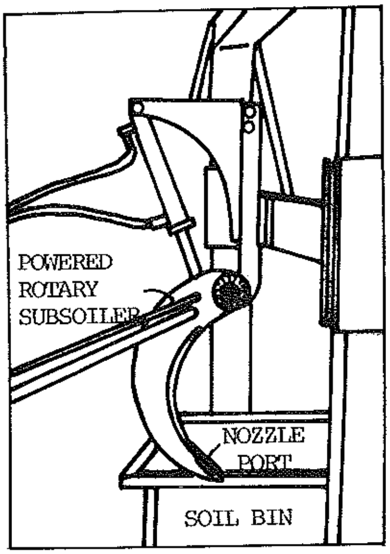

Fig.4 Rotary subsoiler with pressurized sewage sludge injection used in soil bin study.

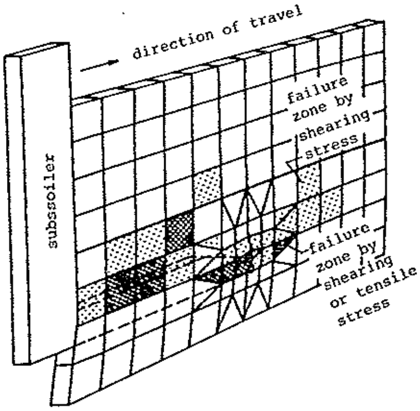

Fig.5 Displacement and stress field after 5 cm subsoiler movemet injecting sewage sludge of 320 g/s in soil having 15% moisture.

secured except when the operating speed is extremely slow, e.g., 1.6 cm/s or less. For instance, when the operating speed is 26 cm/s and flow rate of injected sludge is 410 g/s, the mean draft reduction is 250 daN for a base draft of 800 daN and the reduction of tractive power is 0.65 kW. Since, in this case, the base tractive power was 2.08 kW and the power required to inject sludge was 43.3 W, a reduction of 0.607 kW (about 30 %) was possible. If the flow rate of injected sludge is set at 410 g/s, the traction speed at which the rate of reduction of traction power becomes maximum is 26 cm/s.

ROTARY SUBSOILER Since one of our primary objectives was to reduce the draft power requirements, a low rotary speed, and forward direction of rotation (down-cutting) were necessary (Hendrick and Gill, 1971(a), 1971(b)).

The results of the subsoiler tests for a λ of 6.52 are shown in Fig.9. When sludge was injected at a rate of 465 g/s, maximum pressure at the nozzle port was 30 kPa, which is a practical pressure for farm machinery. A maximum torque of 190 daN·m was required when no sludge was injected. The maximum torque was reduced to 70 daN·m when sludge was injected through the nozzle. When sludge was injected, a cavity was formed in the soil and the sludge was disrupting some soil in front of the blade. No clear soil shear planes had formed.

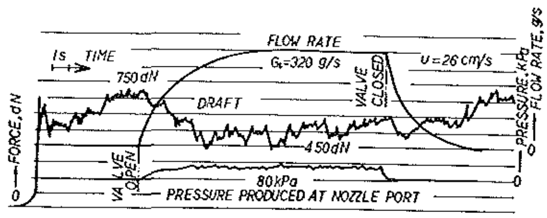

Fig. 6 Oscillogram showing recordings of experimental variables.

The mean torque, the mean draft per revolution, and the power required for the forward rotating subsoiler are shown in Fig.10. These values were obtained by integrating the areas under the torque-rotation and the draft-rotation curves (shown in Fig.9) from blade rotation angle α equal 0.52 rad to α equal 1.57 rad and dividing by 1.05 rad. Since a field machine would have several blades, each blade would cut a smaller slice of soil and the torque and draft would be smaller than those shown in Fig.10. Without sludge injection, the mean torque and draft decreased with a decreasing λ. When sludge was injected, both mean torque and draft were nearly constant over the range of λ studied, and both were always smaller than those for no sludge injection. The power required for the forward rotating subsoiler was less than that for a drawn subsoiler for λ < 4.0, with or without sludge injection. The rotary blade was held rigid in the soil bin to simulate a drawn subsoiler. When sludge was injected, the total power was reduced by 1/2 at a λ of 6.5. However, at a λ of 4.0 the total powers were the same because the power of 1.4 daW to inject the

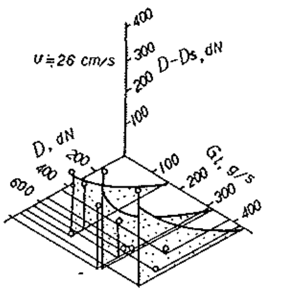

Fig. 7 Draft reduction as a function of operating speed and flow rate of injected sewage sludge.

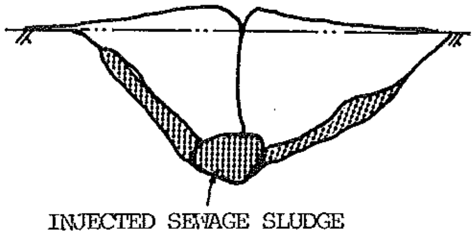

Fig.8 Cross section of soil path distributed by subsoiler.

sludge was constant regardless of the value of λ. For a λ < 4.0 the total power of the sludge injection system was greater than that required for a non-injection system (Araya, 1987).

When the blade had reverse rotation and sludge was injected starting at 1.57 rad of blade rotation, a cavity was formed in the soil and upheaval of the soil surface was observed. The sludge pressure at the nozzle port was about 30 kPa. The sludge disrupted the soil in front of the blade in the same manner as for forward rotation. The reverse rotating subsoiler always required more power than the forward rotating subsoiler when sludge was injected.

CONCLUSIONS

This paper reports the draft reduction and the power reduction of a drawn subsoiler and a rotary subsoiler when sewage sludge was introduced under pressure from the tip of a subsoiler chisel or a rotor tip into soil layer. Since the sewage sludge was viscous and had a high resistance to permeability, the failure produced in the soil was large and a large draft reduction could be expected. These subsoilers would be evaluated in improving heavy clay soil. The main results were as follows;

1. With a drawn subsoiler, when the sewage sludge was introduced under pressure into the soil layer, the resistance to flow of the sludge through the soil produced a reactive pressure on the nozzle port. The maximum pressure was about 0.1 MPa, which was not very high.
2. The draft reduction of the drawn subsoiler caused by injecting sludge was affected by the operating speed, the flow rate of injected sludge and the base draft when no sludge was injected.
3. With the drawn subsoiler, when the operating speed was extremely slow, e.g., 1.6 cm/s or less, the sludge barely disrupted the soil and most sludge flowed out to the subsoiler path along the surface of subsoiler. In cases when a lubricating effect on the subsoiler by sludge occurred little draft reduction was produced.
4. The stable draft reduction could be observed when the operating speeds varied from 6 to 26 cm/s, but at an operating speed of 50 cm/s, little draft reduction was realized because of insufficient injected sludge.
5. When the operating speed of the drawn subsoiler was 26 cm/s and the draft was 800 dN, the base tractive power before injecting sludge was 2.08 kW. If sludge was injected at a flow rate of 410 g/s,

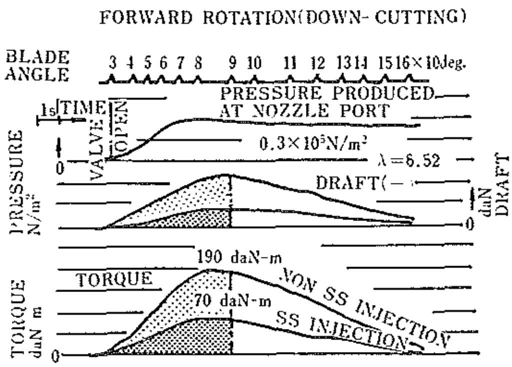

Fig.9 Oscillogram showing experimental variables when sewage sludge is introduced.

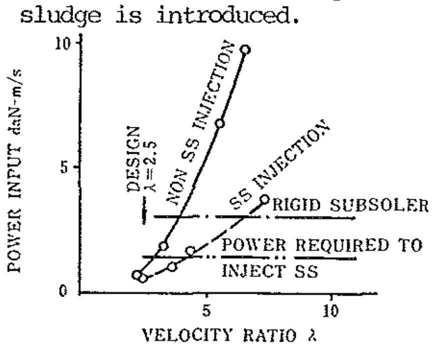

Fig.10 Total power of forward rotating blade in sand at a forward speed of 1.5 cm/s, and varying rotary speed over a range of λ.

the draft was reduced by 250 dN and the tractive power was reduced by 0.65 kW. Since the power required to inject the sludge was 43.3 W, a reduction of 0.607 kW (about 30 %) was possible.

6. With a rotary subsoiler, the sludge formed a cavity in the soil and caused upheaval of the soil surface regardless of direction of rotation.

7. The maximum pressure at the rotating tine tip that was required for sludge injection was 30 kPa. This is a practical pressure for field machinery.

8. With the rotary subsoiler, for forward rotation, when sludge was injected both the torque and the draft were reduced. The reduction was nearly constant for λ ranging from 2.5 to 6.5. At a λ of 6.5 the power was reduced by 1/2 when sludge was injected.

9. When injecting sludge, the power required for the forward rotating subsoiler was less than that required for the reverse rotating subsoiler.

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THE DETERMINATION OF PLOW DRAUGHT FROM SOIL PENETRATION RESISTANCE

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ABSTRACT

This paper presents the results of a study to determine the effect of the geometrical shape of the moldboard bottom and cone index, as a measure of soil strength, on specific plow draught. Measurements of the draught of two differently shaped moldboard bottoms for three soil types were carried out. Plow bodies had a tail angle of 0.79 rad and 0.77 rad and a steepness of 0.94 and 0.58 respectively. The moldboard bottoms were operated at three depths: 0.18 m, 0.23 m, 0,28 m and at constant forward speed: $V=1,8\ ms^{-1}$.

The test results confirm that the steepness of the moldboard surface has a noticeable effect on plow draught, especially on light soils. Graphs are presented, which relate measured specific plow draught and cone index to enable a more accurate prediction of the plow draught.

INTRODUCTION

Plowing remains still one of the most energy-consuming operations in arable farming. Thus, the problem of prediction of plow draught, because of its importance for machinery selection procedures, has been of interest to researchers for many years. A number of questions relating the plow resistance with soil strength, geometrical shape of the moldboard and travel speed were developed. Most of them based on formula developed by Goryachkin (Bernacki et al., 1967). The specific resistance (K) of the plow body is expressed by that well known formula in the following equation

$$K = K_0 + \varepsilon \cdot v^2 \tag{1}$$

The first component equals the specific resistance of the bottom at plowing speed V=0, expressing the soil strength. The second term expresses the dynamic resistance of the bottom, resulting from acceleration of the soil mass moving over the moldboards and of the energy necessary for throwing the soil mass aside and forward. Thus, the latter term incorporates forward velocity V and coefficient of dynamic resistance ε , which depends on the setting angle of the wing of the moldboard θ_s. This angle together with the steepness of the plow body, expressed by the relation L/H (Fig. 1), describe the shape of the plow bottom.

Oskoui et al. (1982) have reported on work relating the quasi-static component of specific plow draught with cone penetration resistance.

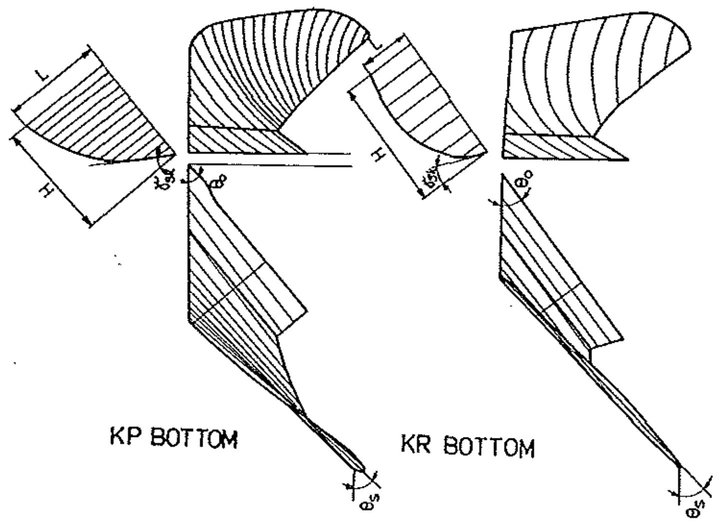

Fig. 1. Profilograms of tested plow bottoms.

The equation developed expressing this relationship is

$$K = K_1 CI + K_2\ \gamma\ v^2 (1 - \cos\ \theta_s)/g \qquad (2)$$

where
CI = cone index,
K_1 and K_2 = empirical coefficients,
γ = soil specific weight.

In both equations the effect of the moldboard shape on specific plowing resistance was expressed by only one parameter: the tail angel θ_s. This paper describes the preliminary results of some further studies on performance of the plow bottoms with the following objectives:
- to compare the effects of the steepness of moldboard on specific plow draught
- to further verify the possibilities to predict the specific plow resistance from the cone index and from the setting angle of the wing of the moldboard for plow bodies with different steepness.

It must be emphasized that since these results are for only one of a two year set, the statistical analysis will not be complete until all results have been gathered.

MATERIALS AND METHODS

Moldboard bottoms. In experiment two types of moldboard bottoms were studied (Fig. 1). The plow body KP was equiped with standard cylindrical moldboard and the KR body with a steep cylindrical one. The details of the geometrical shape of both moldboard bottoms are given in Table 1, bodies were fixed to the one bottom plow U-041.

Measurements. The draught of the plow was measured with a strain gauge dynamometer frame T1, mounted between the plow and the three-point linkage of the two-wheel-drive tractor Ursus C-360. The recording equipment was installed on field laboratory vehicle, driven alongside the tractor.

Table 1. Details of the plow bottoms

Main parameters	Type of plow bottom KP	KR
Load angle α (rad)	0.349	0.401
Cutting angle γ^{sk} (rad)	0.541	0.558
Setting angle θ_0 (rad)	0.663	0.698
Length of the share B (m)	0.523	0.580
Tail angle θ_s (rad)	0.785	0.773
Slope of the moldboard L (m)	0.390	0.245
Height of the moldboard H (m)	0.415	0.425
Steepness of the moldboard L/H	0.940	0.580

The soil strength was measured with a hand penetrometer (manufactured by Agrophysics Institute in Lublin). Two cones, with a tip angle of 0.52 rad, and base areas of respectively 162 mm^2 and 323 mm^2 were used. The six cone index values were determined at 0.05 m intervals to a maximum depth of 0.30 m in each soil. The penetrometer measurements were replicated 10 times per plot.

The bulk density and water content measurements were made in soil cores (0.05 m diameter) taken at three positions (0.05, 0.15 and 0.25 m) below soil surface. The measurements were also replicated 10 times on each experimental plot.

Soils. The experiment was carried out on different soils: light soil, a medium firm soil and a heavy soil. Details of the soils are shown in Table 2.

Table 2. Details of soils

Particle size distribution (%)	Type of soil: Silty fine sand GBL	Sandy clay GL	Clay GC
> 1 mm	2	1	0.5
1 ÷ 0.1 mm	75	21	32
0.1 ÷ 0.02 mm	18	48	22.5
< 0.02 mm	5	30	45
Water content (% W/W)	14.6	14.4	15.3
Bulk density	1.35	1.59	1.56
Soil surface	grass	stubble	bare

Procedure. Test runs were performed in one direction across the field at three different depths of plowing with both types of the moldboard. The plowing depths were 0.18 m, 0.23 m and 0.28 m. On the field marked as GBL (see Table 2), continuous records were obtained for plow draught, over a distance of 50 m, for each plowing depth. On soils GC and GL the lengths of the test runs were 75 m. Each run was carried out at a forward speed of approximately 1.8 ms^{-1}. Forward speed, working depth and furrow slice width were recorded during each run.

RESULTS AND DISCUSSION

The mean values of the plowing draught, the cross sectional area of the furrow at various depths and specific plow resistance for both moldboard bottoms on all three sites are summarized in Table 3. From Table 3 it can be seen that the specific plowing resistance of the steeper moldboard KR is higher than that of KP. It is interesting to note that the largest difference between the mean values, up to about 59% were found on the light soil. This indicates that the difference in draught between these two moldboard bottoms is probably due to the higher pressure exerted by the surface of the more steeper moldboard bottom KR on the soil mass, which is responsible for the friction of the furrow slice on the share and on the moldboard.

Based on the results of a number of penetation resistance tests, the average values of the cone index over a plowing depth and these for the median depth were derived and summarized in Table 3.

Table 3. Results of measurements

Type of soil	Type of Bottom	Depth of plowing (m)	Plowing draught (kN)	Sectional area of slice (m^2)	Specific draught (MPa)	Actual speed (ms^{-1})	Cone index (MPa) FOSA	Cone index (MPa) FA
GBL	KP	0.21	3.26	0.08	4.1	1.9	0.68	0.73
		0.24	3.60	0.09	4.0	1.8	0.73	0.76
		0.26	2.64	0.083	3.2	1.8	0.76	0.76
	KR	0.17	2.37	0.055	4.3	1.9	0.61	0.73
		0.24	4.62	0.072	6.4	1.8	0.74	0.76
		0.27	5.64	0.078	7.2	1.8	0.78	0.80
GL	KP	0.20	1.45	0.075	1.9	1.6	0.65	0.66
		0.23	1.50	0.086	1.7	1.5	0.67	0.73
		0.28	2.77	0.115	2.4	1.5	0.75	0.86
	KR	0.19	1.41	0.073	1.9	1.5	0.45	0.66
		0.23	2.43	0.095	2.6	1.5	0.67	0.73
		0.28	3.26	0.111	2.9	1.5	0.74	0.85
GC	KP	0.19	4.30	0.07	6.1	1.7	1.23	1.15
		0.23	3.85	0.082	4.7	1.7	1.23	1.13
		0.28	7.50	0.11	6.8	1.6	1.22	1.18
	KR	0.18	4.70	0.06	7.9	1.8	1.21	1.15
		0.21	5.60	0.075	7.5	1.7	1.24	1.15
		0.27	6.30	0.099	6.4	1.7	1.22	1.16

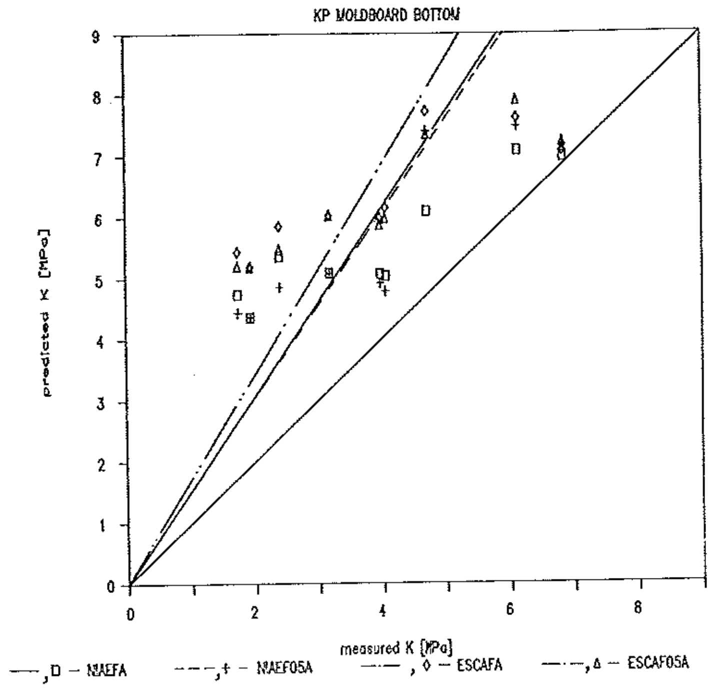

Fig. 2. Measured and predicted values of specific plow draught using the NIAE (K_1=50, K_2=9.66) and the ESCA (K_1=37.59, K_2=23.90) coefficients.

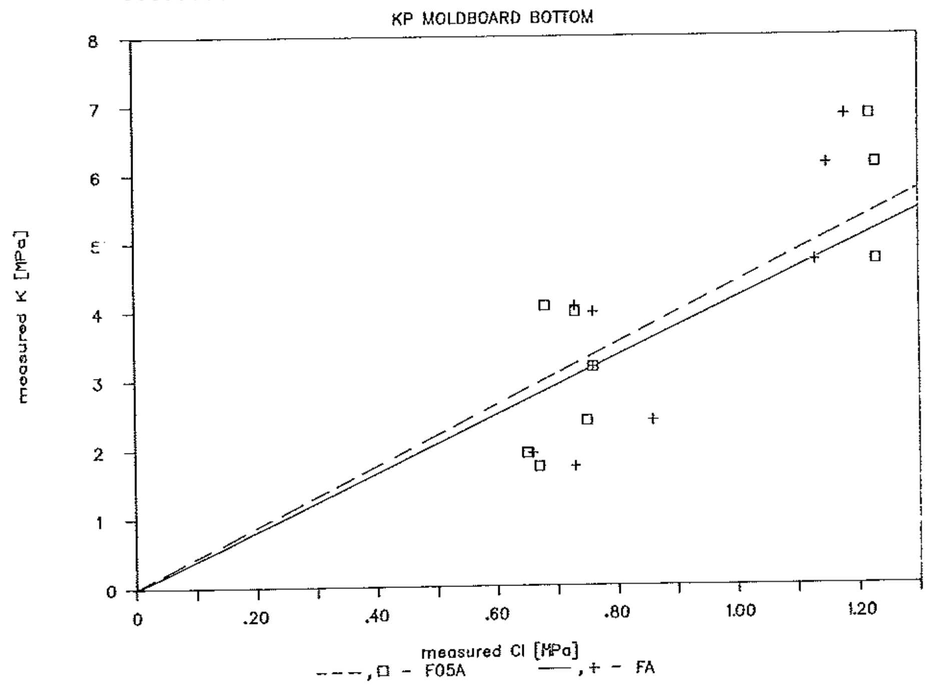

Fig. 3. Relationship between measured values of specific plow draught and cone indices.

Results shown in Table 3 indicate that the mean values of cone index averaged for each plowing depth and for each medium depth of plowing do not differ much. Based on these results the specific draught was calculated, using the equation (2). For every measured value four predicted values were derived by adopting different values of the draught coefficents K_1, K_2 (from the ESCA and from NIAE field test data) (Oskoui et al., 1982), A comparison between measured and predicted specific plow draught is given in Fig. 2. It has been found that there was general over-prediction. The level of over-prediction, shown by means of straight approximation lines, depends strongly on the type of plow body used.

The largest over-predictions, about 55%, occurred for the KP moldboard bottom. It was found, that prediction was improved when the draught coefficients of NIAE and cone indices at median depth of plowing were used, but still there was a considerable discrepancy between measured and predicted values. Thus, it means, that a need to find a more comprehensive equation, which takes into account different geometrical shapes of moldboard bottoms still remains.

In Fig. 3 the experimental relationship between measured specific draught and cone indices for the KP bottom is shown. Such graphs seem to be very useful to predict plowing draught, for certain type of plow body, from cone indices, as long as methods to predict specific plow draught more accurately, remain elusive.

CONCLUSIONS

1. In this study, a better agreement between predicted and measured specific plow draught occured when NIAE draught coefficients were adopted.
2. The test results presented here confirm that the steepness of the moldboard surface has a noticeable effect on plow draught, especially on light soils.
3. The proposed method for estimation of plow draught from specific plow draught-cone index graphs seems to be useful at present when more accurate methods are not available.

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EFFECTS OF DESIGN AND KINEMATIC PARAMETERS OF ROTARY CULTIVATORS ON SOIL STRUCTURE

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ABSTRACT

In comparison with drawn implements, rotary cultivators are of particular interest in final seedbed preparation. In this paper, a quantitative basis for description of soil structure created by rotary tillers is given. Undisturbed Ap horizon samples were collected, impregnated with polyester resin, sectioned by sawing and analysed by means of a Quantimet 720 image analysing computer. Total porosity, area and size of pores were related to design and kinematic parameters of the rotary cultivator, arising from an analysis based upon the location of instant centers of velocity.

INTRODUCTION

In the last years machines for seedbed preparation with driven rotary tools have gained more and more importance in comparison with drawn seedbed combination. Several reasons may explain this development:
1. present-day tractors develop more power than they can transmit efficiently to a draft implement through the tires;
2. the soil breakup created and the easy combination with other machines (f.i. sowing-machines) allow a reduced number of passages;
3. some control over the degree of pulverization is possible.

A sizeable body of literature exists in the field of seedbed preparation with multipowered rotating tools. Much of this literature generally covers kinematics or investigates energy requirements. Hendrick and Gill (1978) give a theorical analysis of the motion for a machine having its axis parallel to the soil surface and perpendicular to the direction of motion. Kinzel and al. (1981) present equations easily programmed for a graphical representation of the relative motion of a rotary tiller blade with respect to the trochoidal path of the cutting edge. The main objective of Stroppel and Reich (1982) is to analyse power-requirements of two kinds of pto-driven machines with rotating tools. Perdok and Vermeulen (1983) develop theoretical models predicting the specific energy demand for different designs of tillage tools, and especially for rotary tillers.

Concerning the effects of these machines on soil structure, there is less literature. Most of the researchers use a simple method that is easy to use but rather imprecise which consists in the measurements of clods size. Hence, the aim of this study is to use a more quantitative basis for the description of soil structure resulting from the action of pto-driven machines with rotating tools, in relation with their design and kinematics parameters. To appreciate the real soil structure, we have used a technique presented by Dexter (1976 and 1979) which consists of impregnating tilled soil samples with paraffin wax, sawing them to see the arrangement of soil particles and associated voids. In contrast to this method, a computer-assisted pore analysis was performed. The present study concerns a rotary tiller with vertical axis, fitted with a crumbler roller.

KINEMATICS

Any point on the rotor travels a path which is a combination of the machine forward motion and the distance from the rotational axis to the point of interest. Assuming that the starting point is with the rotor axis at the origin of the reference axis (Fig. 1), the parametric equations which describe the path of extremity points A and B of rotor are:

$$x_A = v\,t + R\cos\omega t$$

$$y_A = R\sin\omega t \qquad (1)$$

and

$$x_B = v\,t - R\cos\omega t$$

$$y_B = -R\sin\omega t \qquad (2)$$

with R = rotor radius;
t = time;
v = machine forward velocity;
ω = angular velocity of rotor, positive when the rotor rotation is counterclockwise;
$\alpha = \omega t$ = displacement angle.

These equations can easily be programmed for a graphical representation of the path of the tines, showing the effects of changes in kinematic parameters.

A useful approach for analysing the kinematics of a rotary tiller arises from the location of instant centers of velocity. Instantaneously, all points in a rigid body have the same angular velocity about the instant center (IC). Considering figure 1, the instant center of rotor AB is located at the intersection of the drawn lines perpendicular to the velocities of A and O (or B and O).

- The velocity of O is $\vec{v}$, forward motion of the machine;

- The velocity of A is $\vec{V}_A$, which is obtained by composition of forward velocity and peripheral velocity $\vec{U}$, with $\vec{U} = \vec{\omega}\,R$.

The magnitude of the velocity at any point is the product of radial distance to the point from IC times the angular velocity $\vec{\omega}$. Hence, we can write:

$$\vec{v} = \vec{\omega}\,a\ . \qquad (3)$$

From this, knowing that $\vec{v}$ and $\vec{\omega}$ are constants, it follows that IC always lies on a straight line ox' parallel to x-axis, with $y = a$ as equation. One may thus consider that the path of a tine is similar to that of a circle rolling without any slip on the x'-axis: it is a cycloid.

The equations of this cycloid expressed to x' and y-axis are:

$$x = a\,(\,t - \lambda\sin\omega t\,)$$

$$y = a\,(\,1 - \lambda\cos\omega t\,) \qquad (4)$$

with $\lambda = \dfrac{U}{v}$.

If $\lambda = 1$, we have $a = R$. $\lambda < 1$ is the most frequently encountered case with rotary tillers. For a given value of R, an increase of λ is obtained by decreasing forward speed or increasing angular speed of the rotor. In practice, the former is varied by the tractor gearbox, the latter is affected by the selection of gears in the bevel box assembly and/or sprockets in the chain drive assembly.

The crumbler roller fitted to the rotary cultivator completes the action of the rotors. It is intended to break surface clods, improve consolidation and level out the seedbed. When the implement moves forward at high speed, the roller is driven with a negative slip and the points of contact between soil and roller become more spaced, ensuring a decrease in soil consolidation.

CHARACTERIZATION OF SOIL STRUCTURE CREATED BY A ROTARY CULTIVATOR

From above considerations, it is clear that a high value of λ corresponds to closer passages of rotating tines in the soil and thus ensures a greater pulverization. On the other hand, a decrease of λ leads to diminution in soil breakup (Fig. 2).

An experiment was designed with the aim of comparing soil structure created by the rotary cultivator, working at two different values of λ: 2.34 and 3.77. The soil studied can be described as silt loamy soil with a textural B horizon (Aba), relating to the serie level of the Belgian Soil Map in which the three main letters successively represent the nature of parent material or the texture, the moisture class and the profile development. The results presented here are issued from an experimentation realized in April 1985, when the moisture content was 16 %. The soil was tilled conventionally: after ploughing in February 1985, a spring-tine cultivator was used to shatter the soil in April 1985; increased pulverization was obtained by a rotary cultivator to a depth of 10 cm; this treatment was followed by the passage of a ridged roller, improving consolidation, before the sowing of beets. 4 repetitions were made and 10 undisturbed samples were collected from the Ap horizon of each set of plots, before and after the passage of the rotary cultivator, and after the passage of the sowing machine.

The samples were dried in a drying-room, at 40 °C: for a small content in clay and in organic matter, this low temperature ensures the departure of water without altering soil structure. When dried, the samples were impregnated with a polyester resin containing white pigments, sawed and photographs were prepared for analysis by the image-analysing computer (8 $\times$ 6 cm), Quantimet 720. This one consists of:
- a sensor (a video-scanner);
- an analog/digital converter which electronically converts the analog TV signal into an array of squares, called "pixels"; each of them is defined by two spatial coordinates and a "gray-level" intensity value;
- a processor.

PORE ANALYSIS

The pore-complex was identified thanks to the white color, leading to easy quantification by means of measurements including total porosity, area and size distribution of pores. Total porosity is here defined as the proportion of white pixels to total pixels in the scene. The porosity value estimated in this way need not be the same as porosity measured by physical tests because unconnected pores, as well as pores beyond microscopic resolution are not detected. In our case, the length of the smallest element detected is 170 µm. Table I gives, for layers of 1 cm thickness, the evolution of porosity with depth before and after the passage of rotary cultivators, and after the passage of sowing-machine.

The loosening created by the former essentially results from the creation of internal rupture surfaces, the lifting of soil blocks falling after the passage of tines. This effect is emphasized by the flexibility of tines in spring steel. It is also interesting to point out the sorting effect of the implement, resulting from the falling of small clods.

In the action of rotary cultivators, dynamic forces play an important role: soil clods are broken up by the impact suddently applied by a rotating tine and transmit a part of the shock to their neighbours, which are split in turn. So cracks are propagated in the environment.

Table I. Evolution of soil porosity with depth and with the treatments (%).

Depth (cm)	Spring-tine cultivator	Rotary cultivator (λ = 2.34)		Rotary cultivator (λ = 3.77)	
		Before sowing	After sowing	Before sowing	After sowing
0 to - 1	42.2	31.4	30.9	33.8	28.
- 1 to - 2	21.9	19.8	6.7	20.1	6.8
- 2 to - 3	15.4	14.4	4.7	14.6	3.0
- 3 to - 4	18.3	14.5	3.0	9.9	2.6
- 4 to - 5	19.8	11.3	5.0	5.5	1.9
- 5 to - 6	15.5	14.8	5.8	5.6	4.1
- 6 to - 7	17.2	13.2	6.4	6.2	4.8
- 7 to - 8	15.4	11.4	5.1	5.5	11.6

From Table I, it appears that porosity resulting from the passage of a rotary tiller with λ = 3.77 is considerably less than that of a rotary tiller with λ = 2.34. The intensive soil pulverization created by the rotors of the former was followed by an important consolidation of the crumbler roller. This consolidation is improved by the ridged roller and measurements made after the passage of the sowing-machine show strong differences in structure of the resulting tilth between plots corresponding to λ = 2.34 and 3.77.

Area and size distribution of pores determine various physical properties important to plants, they especially affect water infiltration rate and storage capacity. Fig. 4 gives area distribution of pores, according to depth. They show that the highest proportion of pores is located between 0.1 and 0.2 mm^2. This proportion of rather small pores is greater for plots with λ = 3.77. Furthermore, the smaller standard deviation around the mean value of the area suggest a greater homogeneity for these plots.

Size of pores was measured by using a form factor C, which is represented by:

$$C = 2\frac{\sqrt{\frac{S}{\pi}}}{\frac{P}{\pi}}$$ with S the area and P the perimeter.

For elongated pores, (L = 10 l), this ratio is < 0.60 while for very rounded pores, it is about 1. Fig. 5 gives the distribution of pores. From the computations relative to size distribution of pores, it appears that the most frequently encountered pores have a form factor between 0.8 and 0.9, in the top layer as well as in deeper layers. One may consider that more than 70 % of the pores have a C value comprised between 0.7 and 1, that is to say they are rather rounded.

CONCLUSION

Using a rotary cultivator with a high ratio of peripheral velocity to forward velocity leads to a lesser total porosity that is more homogeneous. Are these conditions favourable for plant germination? we already possess two elements of the answer: small seeds, like sugar beet seeds, need close contact with soil to germinate and thus fine structure is favourable. On the other hand, a seedbed constitued of too smaller sized clods presents the *risk of creating soil crusts, in certain circumstances.*

ACKNOWLEGMENTS

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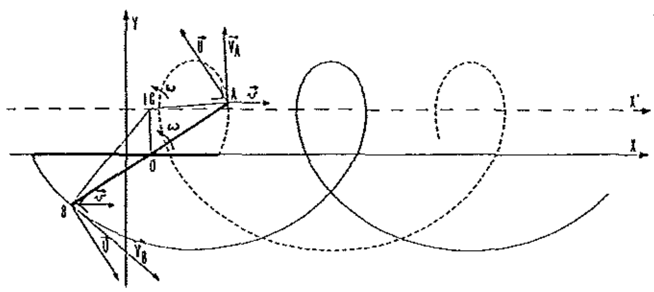

Fig. 1. Graph of the path of the two extremity points of the rotor

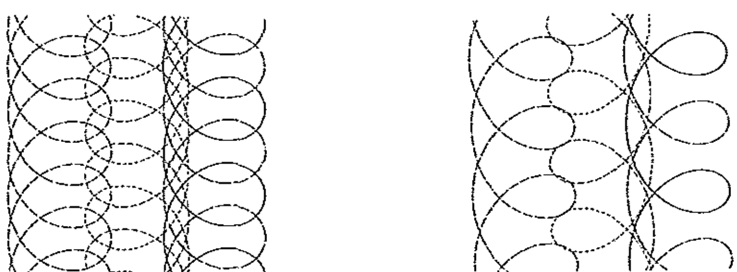

Fig. 2. Graph of the paths of the tines belonging to three contiguous rotors (on the left, $\lambda = 3.77$ and on the right $\lambda = 2.34$)

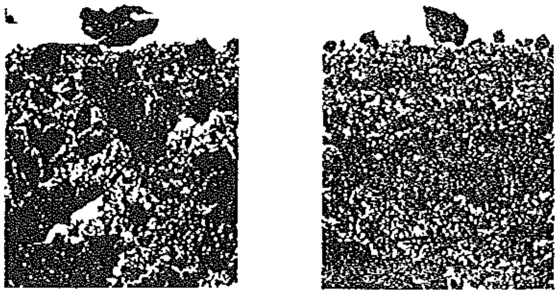

Fig. 3. Photographs of the sections of tilth produced by spring-tines cultivator, rotary tillers with λ = 3.77 and 2.34

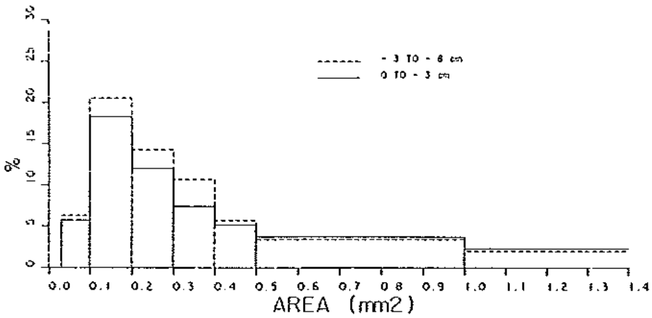

Fig.4. Area distribution of pores after the passage of rotary harrow (λ = 2.34), ridged roller and sowing-machine

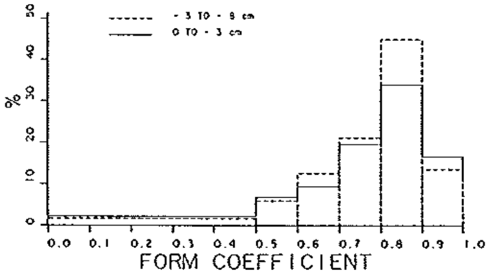

Fig. 5. Form coefficient distribution of pores

THE EFFECT OF LOESS SOIL MOISTURE AT THE MOMENT OF CULTIVATION ON MOULDBOARD PLOUGH AND ACTIVE TOOLS ACTION RESULTS

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ABSTRACT

The study was concerned with the effect of tillage by means of a mouldboard plough and active tools with a soil crumbling element driven from the power takeoff shaft on the physical properties of loess soil. The study was conducted within a broad range of soil moisture values. It was found that active tools, as compared to the plough, cause greater changes in the soil bulk density, total porosity, field air capacity, and content of pores of diameters greater than 30 µm, with relation to the pre-tillage conditions. The best tillage results, both for the mouldboard plough and for the active tools, were obtained when the soil moisture was from 12 to 17% (w/w) which corresponds to 45-65% with relation to the field water capacity of the soil.

INTRODUCTION

At present, basic soil tillage is being performed not only by means of a plough but by other type of tools. At most these are active tools that crumble strongly and mix up an arable horizon (Hendrick and Gill, 1971; Dechnik and Lipiec, 1975; Nowicki et al., 1980), or the tools of chisel type cultivate the soil deeply without ridge turning over (Bilanski, 1964).

Soil water content affects in a considerable rate both the ploughing resistance and the agrophysical effects of the work (Ralczew, 1967; Domżał, 1971). The results obtained from our researches carried out on soil of loamy granulometric composition show that the effect of tillage performed with a plough and active tools are much differentiated due to soil moisture (Domżał et al., 1981). Therefore, further studies were undertaken to assess the character and extent of the effect of loess soil moisture on the properties of the soil following tillage by means of a mouldboard plough and active tools.

METHODS

The study consisted in comparing the agrophysical effects of the work of a mouldboard plough and active tools provided with a soil crumbling element driven from the power takeoff shaft. The study was conducted on a brown soil developed from loess, performing tillage measures within a broad range of soil moisture values, from 6% (w/w) to 22% (w/w) . This range covers all moisture conditions under which tillage is performed on loess soils. All tillage measures were performed on the same field.

The soil on which the study was conducted had the granulometric composition of a loess silt with a 65% content of particles of diameters from 0.1 to 0.02 mm and a 32% content of particles of diameters below 0.02 mm. The content of humus in the arable horizon was 1.75%, the limit of plasticity was 24.2% (w/w), the limit of liquidity - 28.2% (w/w), and the index of plasticity - 3.8% (w/w). The field water capacity of the soil in a rested state, determined at a suction force pF 2.5 (30.98 kPa) was within a range from 26 to 28% (w/w).

Samples for the determination of the physical properties of the soil were taken immediately after the tillage, into metal cylinders 100 cm^3 in volume, from the 0-10 cm layer in 10 replications. The following properties of the soil were analyzed: bulk density, total porosity, water and air capacities, and content of pores of diameters over and below 30 μm. Measurements of the water-air characteristics were carried out on ceramic plates according to Richards.

Results obtained from the analyses were processed graphically and statistically. On the basis of curvilinear regression analysis, an equation was developed, describing the relation of the properties studied to the soil moisture at the time of tillage.

RESULTS

Soil moisture at the time of the application of tillage measures has a strong effect on the properties of soil tilled by means of a plough as well as by means of active tools. The lowest bulk density was obtained as a result of tilling a soil of a moisture of 12 to 17% (w/w). Increased and decreased soil moisture was accompanied by increased soil density, irrespective of the type of tool used, and the relationship can be described by square equations (Fig. 1 A). Over the whole range of soil moisture values under analysis, the bulk density of soil tilled by means of a mouldboard plough was greater than that of soil tilled by means of a rotovator or a milling plough. The minimum bulk density obtained as a results of mouldboard plough tillage was 1.10 Mg . m^{-3}, while the active tools brought the soil to a bulk density of 0.95 Mg . m^{-3}. It is worth noting that within the range of optimum tilling moisture the active tools caused similar changes in the soil bulk density, while in soil of a higher moisture the loosening by rotovator was distinctly stronger than by milling plough.

Changes in the total porosity, a property opposite to soil bulk density, confirm the above regularities (Fig. 1 B). The highest total porosity - 63% (v/v), was obtained after tillage by means of active tools, applied to soil of a moisture of 15% (w/w). Following mouldboard plough tillage at the same soil moisture level, the total porosity reached a value of 58% (v/v). As in the case of soil bulk density, total porosity displays a closer relationship with soil moisture at the time of tillage after the application of a milling plough rather than a rotovator; this is especially notable in the range of soil moisture values higher than the optimum.

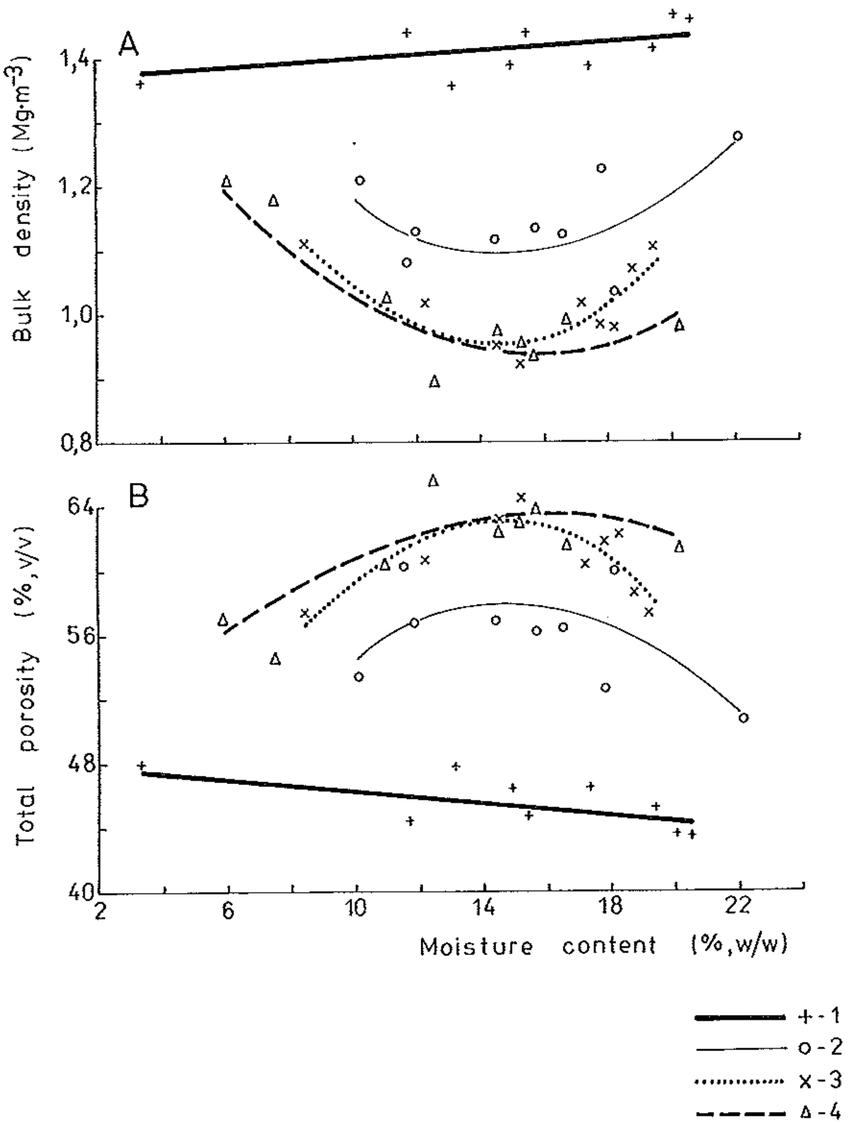

Fig.1. Relationship between moisture content at the moment of soil cultivation and bulk density (A) and total porosity (B) of the arable layer. 1 - before tillage, 2 - after mouldboard plough tillage, 3 - after milling plough tillage, 4 - after rotovator tillage.

Changes in the total porosity are related primarily to changes in the content of the largest pores (diameters over 30 μm). An increase in soil moisture during tillage was accompanied initially by a strong increase in the content of pores of diameters over 30 µm, up to a maximum at a soil moisture level of 14-16% (w/w), followed by a decrease (Fig.2 A). The highest content of macropores was characteristic of the soil after active tool cultivation, and a lower content of macropores - of the soil after mouldboard plough tillage. Particulary strongly differentiated was the effect of work of tillage tools within a range of moistures above 16% (w/w). Under those moisture conditions the content of large pores in the soil increased most strongly after rotovator tillage.

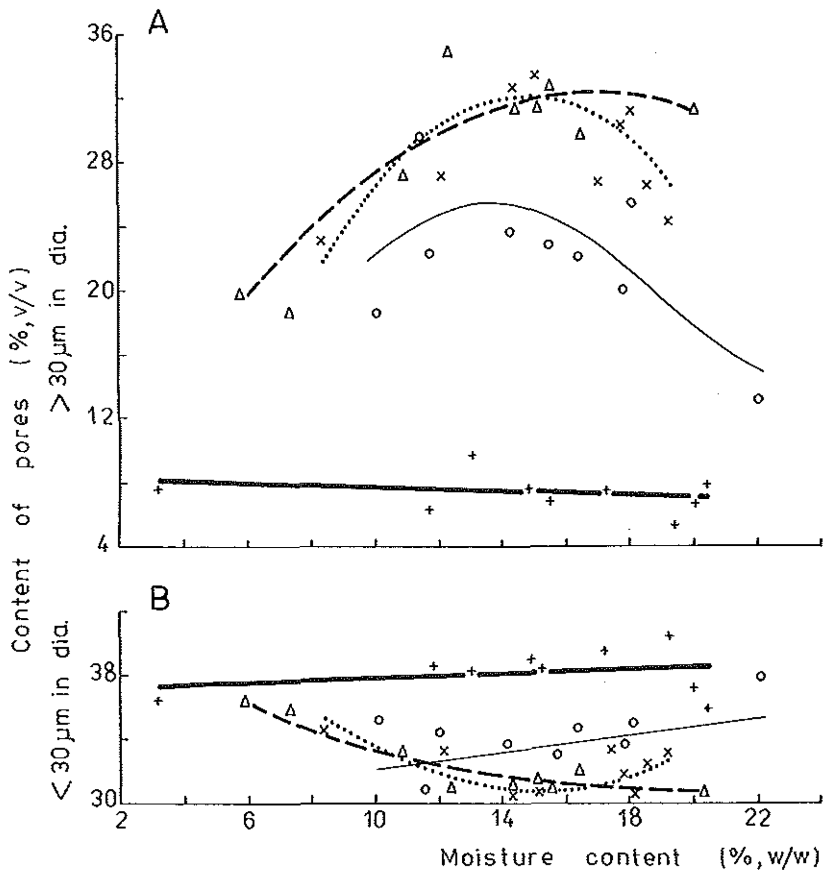

Fig. 2. Relationship between moisture content at the moment of soil cultivation and content of pores > 30 µm in dia. (A) and < 30 µm in dia.(B) in the arable layer. Explanations as in Fig.1.

The relation of the content of pores of diameters less than 30 µm to the soil moisture at the time of tillage is considerably weaker than in the case of large pores (Fig. 2 B). This is understandable, as the content of these pores is determined primarily by the micro-structure of the soil. After the use of active tools the highest content of small pores was observed in a dry soil, while after the application of the plough - in a moist soil.

Of the water and air capacities determined, the present paper presents the field water capacity (pF 2.5 - 30.99 kPa) and the corresponding field air capacity.

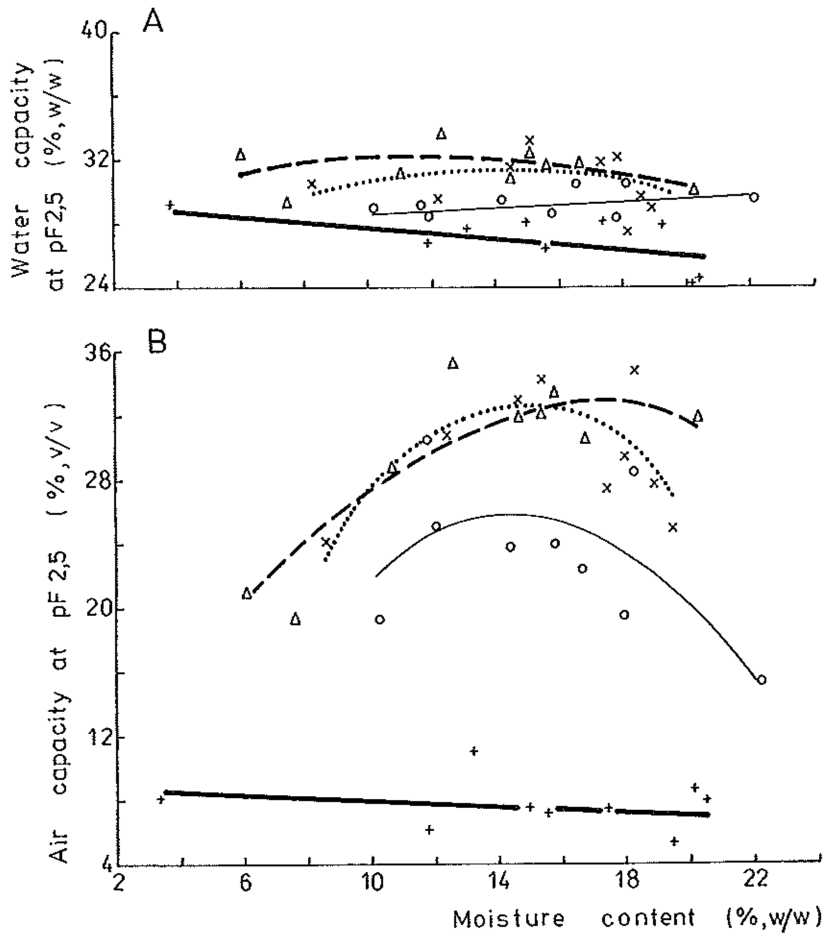

Fig.3. Relationship between moisture content at the moment of soil cultivation and water capacity at pF 2.5 (A) and air capacity at pF 2.5 (B) of the arable layer. Explanations as in Fig. 1.

Field water capacity, which is determined by the water contained in pores of diameters smaller than 10 µm, varied only slightly as a result of tillage, and its relation to the soil moisture at the time of tillage was also weak (Fig. 3 A). The highest values of field water capacity were observed after tillage by means of a milling plough at a soil moisture of 12.5% (w/w) . But tillage by means of each of tools caused considerable increase in the field air capacity with relation to nontilled soil, and the relationship between this property and the soil moisture at the of tillage is very strong and can be described by means of square equations (Fig. 3 B). Also in this case one can observe the same regularities as those described earlier: the effect of the work of the mouldboard plough was weaker, and that of the active tools was stronger. In a wet soil the rotovator caused distinctly greater changes in the field air capacity than did the milling plough.

CONCLUSIONS

(1) The differences in the effects of the work of active tools (milling plough and rotovator) as compared to those of the mouldboared plough were expressed by a greater changes in the physical properties with relation to the pre-tillage condition of the soil, and a stronger relation of the effects of tillage by means of a milling plough to the status of soil moisture at the time of tillage.

(2) The best results of tillage, performed by means of a mouldboard plough as well as by means of active tools, were obtained in a soil of a moisture of 12-17% (w/w) which corresponds to 45-65% with relation to the field water capacity.

(3) Of the analyzed physical properties of the brown soil developed from loess, the strongest changing as a result of tillage were the bulk density, total porosity, content of pores of diameters over 30 μm, and field air capacity.

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COMPARISON OF THE SEEDBEDS CREATED BY TWO CEREAL DRILLS UNDER DIFFERENT TILLAGE SYSTEMS

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ABSTRACT

A new prototype cereal drill was compared to a standard cereal drill on a clay loam soil under different tillage systems: direct drilling, minimum tillage and conventional tillage. Soil seedbed conditions were evaluated in terms of soil strength, soil moisture content and seedling development. Soil strength was significantly affected by the tillage treatments whereas gravimetric soil moisture content was not affected. Differences in crop stands, main stem leaves per meter of row and percentage of TO (coleoptilar) tillers were encountered among the tillage and drill treatments. Nevertheless, no statistical difference was found among the crop yields achieved with the treatments considered.

INTRODUCTION

In dryland agriculture one of the main purposes of primary and secondary tillage is to provide seedbeds with adequate moisture, aeration and soil strength for good crop establishment. The assessment of the performance of a drill or a tillage equipment is done by counting the total number of plants emerged. Stand counts taken periodically during the emergence process and expressed as the time required for 50 percent emergence give an indication of the amount of plant stress imposed by the seedbed (Wilkins et al., 1982). For winter wheat Keppler et al. (1982) have developed another method to evaluate the seedbed environment which consists in measuring the number of the main stem leaves of the plant. Once the plant has emerged the rate at which new leaves appear is dependent on the growing degree days available and is not influenced by unfavourable conditions in the seedbed. Therefore, the differences encountered in the number of main stem leaves for seeds planted at the same time is due to nonuniform seedling emergence. Furthermore, Peterson et al. (1982) and Keppler et al. (1982) have found that in unfavourable seedbeds the percentage of plants with TO (coleoptilar) and T1 (first leave) tillers is reduced.

In creating the seedbed environment not only the tillage practices but also the furrow opener of the drill play a major role. In fact, zero-tillage seedbeds are created only by the

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drill furrow openers. Their design and the soil physical conditions have significant effects on direct drilled crops (Choudary and Baker, 1982).

Last year, the Department of Farm Machinery of the Polytechnic University of Madrid, in co-operation with a farm machinery manufacturer, developed a new drill prototype for cereal crops devoted to either cultivated or uncultivated soil whose planting system consists of:

- a stripped coulter to cut the soil even with heavy trash
- a single concave furrow opener disc. Furrow openers placed 170 mm apart
- a roller to compact the soil around the seed

This paper presents the first results of a series of experiments in which the new drill is being compared to other commercially available drills under different tillage treatments. The objective is to compare the seedbed environment created by the new prototype with a standard one in terms of soil strength, soil moisture content and seedling development.

METHODS AND MATERIALS

The experiment was conducted at El Encín Research Station, Alcalá de Henares, on a clay loam soil (21 % sand; 42 % silt; 37 % clay) with 2.0 % organic matter and ph 7.7. Five treatments involving different tillage practices and two drills were considered:

- L1. Direct drilling with the new prototype drill.
- L2. Minimum tillage: chisel plough followed by C-leaf cultivator and sowing with the new prototype drill.
- L3. Minimum tillage: chisel plough followed by C-leaf cultivator and sowing with a standard cereal drill (hoe-type mounted drill with furrow openers 150 mm apart).
- L4. Conventional tillage: mouldboard plough followed by C-leaf cultivator and sowing with a standard cereal drill.
- L5. Conventional tillage: mouldboard plough followed by C-leaf cultivator and sowing with the new prototype drill.

All the treatments were arranged in a complete randomized block design with three replications. Spring barley (cv. Hassan) was sown at a rate of 200 kg/ha (450 plants/m2) on February 24, 1987. Prior to sowing 250 kg/ha of compound fertilizer 8-24-8 were spread as first dressing. A further dressing of ammonium nitrate (26 % in nitrogen) was applied at a rate of 350 kg/ha at mid tillering.

Soil cone resistance was measured weekly from March 3 to April 14 with a soil cone penetrograph down to 20 cm depth. Gravimetric soil moisture content was measured at the same time intervals as soil cone resistance. On May 5 plant samples of each plot were taken to determine crop stand, seed depth, main stem leaves and percentage of plants with T0 and T1 tillers. Crop yield was assessed by hand-harvesting four quadrats of 0.25 m2 in each plot.

RESULTS

Figure 1 shows the average soil cone resistance for the five treatments considered down to 20 cm depth. In the first 10 cm conventional tillage (treatments L4 and L5) resulted in the lowest soil cone resistances followed by minimum tillage (treatments L2 and L3) and direct drilling (treatment L1). At 15 and 20 cm depth no statistical difference was found among the soil cone resistances in the conventional and minimum tillage treatments, and the direct drilling treatment had the highest values.

Soil cone index values are summarized in Table I. In the first 10 cm depth conventional tillage treatments (L4 and L5) and the minimum tillage treatment with the new prototype drill (L2) resulted in the lowest soil cone index values followed by the minimum tillage treatment with the standard drill (L3) and direct drilling (L1). Although a similar trend was observed between 10 and 20 cm depth, the soil cone index values of both minimum tillage treatments were intermediate between the values encountered in the conventional tillage and direct drilling treatments. Gravimetric soil moisture content (Table II) was the same in all the treatments.

Table III summarizes the influence of the tillage treatment and cereal drill on seedling development. The lowest crop stand was achieved with the direct drilling treatment (L1) followed by the minimum tillage treatment with the standard drill (L3) and the conventional tillage treatment with the prototype drill (L5). The highest stands were achieved with the minimum tillage treatment and the prototype drill (L2) and the conventional tillage treatment with the standard drill. The lowest sowing depth was found in the direct drilling and minimum tillage treatments.

The highest values of the total number of main stem leaves per meter of row were encountered in the minimum tillage treatment with the prototype drill (L2) and the conventional tillage with the standard drill (L4), whereas the minimum tillage treatment with the standard drill (L3) had an intermediate value. Direct drilling and conventional tillage with the prototype drill (L1 and L5, respectively) resulted in the lowest values. These figures of main stem leaves per meter of row are not correlated with the percentage of plants with TO tillers. Whereas the prototype drill, both in the conventional and minimum tillage treatments, resulted in the lowest percentage of plants with TO tillers, direct drilling and the standard drill in the conventional tillage treatment resulted in the highest percentage. Minimum tillage with the standard drill was intermediate. Crop yields were the same in all the treatments but the lowest value was achieved with conventional tillage and the prototype drill.

DISCUSSION

The average soil cone resistance and the average soil cone index are more affected by the tillage practices adopted than by the effect of the drill furrow openers. Seedbed environment evaluated in terms of total number of main stem leaves per meter of row showed that the best environments were the ones created by the prototype drill and the standard drill when primary tillage was performed with a chisel plough and a mouldboard plough, respectively. However, in terms of the percentage of plants with TO tillers there was no correlation with the total number of main stem leaves. Direct drilling with the prototype drill resulted in the highest percentage of plants with TO tillers, whereas with the minimum tillage treatment with the prototype drill no TO tillers were encountered. Wilkins et al. (1982) suggested that soil moisture content and depth of sowing contribute to seedbed stress when TO tillers are initiated. Direct drilling resulted in the lowest sowing depth and consequently had the highest percentage of TO produced. But for minimum tillage with the prototype drill this principle did not stand.

CONCLUSIONS

1. Soil strength is affected to a greater extent by tillage than by the effect of the drill furrow openers.

2. Gravimetric soil moisture content till complete crop establishment was the same in all the treatments considered.

3. In terms of total main stem leaves per meter, the new prototype drill resulted in better seedbeds than the standard drill in the minimum tillage treatment. The opposite occurred in the conventional tillage treatment.

4. In terms of percentage of plants with TO tillers, the new prototype resulted in coarser seedbeds than the standard drill both in minimum and conventional tillage.

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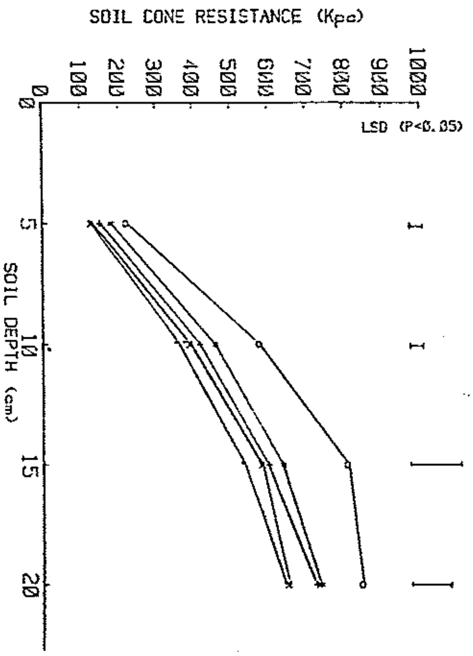

Fig. 4. Average soil cone strength in the five treatments compared. L1 (o——o); L2 (+——+); L3 (*——*); L4 (x——x); L5 (•——•).

Table I. Average soil cone index (KPa) at different depths in the seedbeds compared during total crop emergence.

Soil Depth (cm)	Treatments					LSD P < 0.05
	L1	L2	L3	L4	L5	
0-10	397 c	282 a	327 b	251 a	250 a	43
10-20	622 c	476 ab	502 b	445 a	426 a	50

Table II. Average soil moisture content (%, W/W) in 0-20 cm depth during total crop emergence.

Depth (cm)	Treatments					LSD P < 0.05
	L1	L2	L3	L4	L5	
0	9.9	9.0	8.5	8.5	9.0	N.S.
5	16.9	16.6	17.0	17.1	16.7	N.S.
10	17.0	17.6	17.7	18.6	18.2	N.S.
15	16.7	17.3	17.6	18.1	17.9	N.S.
20	17.1	17.3	17.1	17.6	17.5	N.S.

Table III. Influence of tillage system and cereal drill on spring barley growth[1].

Tillage system	Crop stand Plants/m2	Seed depth (cm)	Main stem leaves/m	% Tillers TO	% Tillers TI	Crop yield (kg/ha) (15 d.m.)
Zero tillage with prototype drill (L1)	273a	3.1a	354a	6.3a	94.5a	2227
Minimum tillage with prototype drill (L2)	333bc	3.4a	424b	0.0b	96.0a	2047
Minimum tillage with standard drill	291ac	3.8ab	324c	4.6ab	97.0a	2473
Conventional tillage with standard drill	321bc	4.2b	422b	6.0a	100.0b	2068
Conventional tillage with prototype drill (L5)	300ac	4.4b	372a	3.2b	100.0b	1736

[1] Figures in each column followed by the same letter are not significantly different.

DEVELOPMENT OF AN INSTRUMENTED TINE FOR USE IN TILLAGE STUDIES

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ABSTRACT

An instrumented tine (chisel) for the study of the dynamic relationship between a tillage tool and the soil was developed. Field experiments were conducted at two different forward speeds and operating depths in two different soil conditions in a Yolo loam soil. A theoretical model which utilized a penalty function technique was developed to analyze the experimental data. The results indicate that the device can be successfully used to predict the soil cutting force distribution over the tillage depth. Moreover, we found that the force distribution over the tillage depth was linear at the shallow depth in both tilled and untilled soils. However, the force distribution was nonlinear at the higher depth in the untilled soil. Furthermore, the device was also used in the study of soil-fracture mechanics. We found that the soil fracture was a very complex process with two or three dominant fracture frequencies. The fracture frequencies depend on the soil condition, operating speed and depth.

INTRODUCTION

The interactions between a tillage tool and the soil is a very complex process. This complexity is caused by the nonhomogeneity of soil coupled with the complex nature in which the soil seems to fail. As a result, attempts to measure the force interaction between the soil and a tillage tool have met with little success.

The objective of this study was to design, fabricate and test a device that can measure the forces acting on it as it moves through the soil. The device was used to investigate two aspects of soil tillage-tool interactions. The first aspect investigated was the way in which the force distribution acting on the device varies with changing soil and operating conditions. The second aspect addressed was the nature in which the forces acting on the device vary with time as the device moves through the soil. From this, the dominant frequencies corresponding to the failure modes of the soil were determined.

INSTRUMENTED TINE DEVELOPMENT

As a tillage tool moves through the soil, there are forces that act on the tool due to the cutting, breakage, and displacement of soil as well as the parasitic (frictional) forces that develop between the soil and tillage tool. In order to measure the resulting force distribution on a tillage tool, a tillage tool had to be instrumented so that the forces acting on it could be determined. To accomplish this force measurement, we decided to instrument a soil chisel with strain gage bridges. Because the strain gages mounted on the chisel would have to work in a hostile environment (in close proximity, if not in contact with soil) extreme care had to be taken in locating the gages. Consequently, a special chisel was fabricated that would allow for adequate protection of the strain gages. The instrumented chisel was equipped with a replaceable cutting edge. This cutting edge was designed to take a majority of the wear due to the interaction with the soil thereby protecting the instrumented chisel from significant wear. In addition, the cutting edge and chisel cross-section were designed in accordance with the ASAE Standard S313.2 for a 323 sq. mm cone penetrometer. This appeared reasonable since the chisel can be viewed as a two dimensional penetrometer. Moreover, a means of measuring the vertical load acting on the chisel was provided by measuring the force required to restrain the cutting edge from vertical movement. Figure 1 illustrates the chisel profile, the cutting edge and the instrumentation.

MODEL OF THE FORCE DISTRIBUTION ACTING ON THE CHISEL

In order to analyze the experimental data, we developed a model for force distribution on the tine. The model consists of a general distribution force $f(x)$ acting over the depth of tillage operation, where x is a reference coordinate originating at the tip of the chisel oriented vertically upwards along the chisel, a point force, $f_o\ \delta(x)$ acting at the tip of the chisel and a heavy side function $H(x-d^*)$ acting over a portion of the operating depth to accomodate sudden changes in soil characteristics. Note that f_o is the magnitude of tip force and d^* is the distance from the tip of the chisel to the onset of Heaviside function. Using a truncated Taylor series expansion for the function $f(x)$, Glancey et al. (1988) developed a multi linear regression technique to analyze experimental results. Since our model used a double integral method and truncation of $f(x)$, it became necessary to employ constraints in the form of an inequality [i.e. $f(x) > 0$ everywhere along the operating depth]. A penalty function approach was used to incorporate this contraint and obtain a physically meaningful solution.

EXPERIMENTAL TECHNIQUES

The chisel was tested at two different ground speeds (0.8 and 3.2 km/hr) and two different chisel depths (152.5 and 305 mm) in two distinct soil conditions for force distribution studies. All tests were conducted in a Yolo loam soil on the University of California Davis campus. The first field was left in oat stubble from the previous winter and the second field was plowed and disked twice. To quantify soil conditions, bulk density, soil moisture and cone index profiles down to 305 mm were developed for each field. Bulk density and moisture measurements were made by taking soil core samples at various depths at two locations in each field. In addition to the core samples, bulk density measurements, over a range of depths, were made at six locations in each field with a Neutron Probe. Cone index measurements were made using a hydraulically driven cone penetrometer with a 323 sq. mm base penetrometer cone mounted on the test tractor. Six cone index samples were made at various locations in each of the two fields. A 2^k factorial experimental design was used with soil condition, operating speed and chisel depth as factors resulting in eight treatment combinations to be tested. Two replications of each combination were performed resulting in sixteen tests. The strain gage data were recorded on a micrologger and subsequently analyzed by a microcomputer. The experiments for soil fracture studies were similar except 100 and 200 mm operating depth were selected.

RESULTS AND DISCUSSION

Force Distribution Prediction: Figure 2 illustrates the typical force distributions for the chsel operating at a speed of 3.2 km/h and a depth of 305 mm for the plowed and oat stubble field. The results indicate that for the plowed soil, the force distribution was linear at both low and high operating speeds at a chisel depth of 152.5 mm, (Glancey et al., 1988). The low and high speed tests in the plowed soil at a depth of 305 mm indicated a hard layer located approximately 185 mm below the soil surface as illustrated in Figure 2. In the oat stubble field, tests with the chisel operating at a depth of 305 mm indicated a unique kind of behavior when compared to the results from the plowed ground. Figure 2, at a chisel depth of 305 mm, indicate first, that there was no hard layer as in the plowed soil and second, that the force distribution was quadratic and not linear.

Soil Fracture Frequency Determination: The measurement of the draft variation on the chisel was achieved by monitoring only the top strain gage (i.e. the strain gage furthest from the tip of the chisel). Figure 3 shows a typical plot of the variation of soil cutting moment with time. A specially developed FFT routine was used to analyze the results. A typical FFT plot is shown in Figure 4. Results for each operating condition were pooled and the dominant fracture frequencies were identified. The frequency for a given mode was then determined by pooling all the frequencies from the different subsets for both replicates for that mode and then averaging them. Our results indicate that the soil failure process consists of more than one dominant frequency. The results from the stubble soil indicate that there were three distinct fracture modes for the tests run at 3.2 km/h and a depth of 100 mm. However, an increase in operating depth to 200 mm eliminated the third fracture mode in the soil. This seemed not to be the case when operating at 0.8 km/h. When the operating depth was increased from 100 mm to 200 mm at this lower speed, the fractures distances did decrease, however, the three distinct modes of fracture were still evident. In the plowed soil conditions at an operating depth of 200 mm, only two fracture frequencies were dominant at both operating speeds. It appears that soil failure consists of both major cracks as well as minor cracks. The major cracks seem, for the most part, to form ahead of the chisel (i.e. in the direction of travel) while the minor cracks appear to form laterally off of the major cracks. This process was complicated by cracks that were already present in the soil due to the shrinkage of the clay as the soil dried over the summer.

CONCLUSIONS

Based on this study, we reached the following conclusions:

1) An instrumented chisel for use in tillage studies has been developed.

2) The chisel can be used to successfully determine the variation of cutting force over it's operating depth using a mathematical model that incorporates a penalty function approach to obtain a physically meaningful solution using a constrained optimization technique.

3) The force distribution over the chisel operating depth was found to be linear for low and high operating speeds at shallow depths (150 mm) for both tilled and untilled soil.

4) The force distribution was found to be nonlinear when the chisel was operated at a depth of 305 mm for both a low and high operating speed in an untilled (uniform) soil.

5. When the chisel was operated at a depth of 305 mm in a plowed soil, the force distribution showed a discontinuity at a depth corresponding to the prior tillage depth.

6. The instrumented chisel can be used to detect the fracture modes of the soil using a Fast Fourier Transform technique.

7. The failure of soil was found to be quite complex consisting of two to three dominant modes of failure.

8. The fracture frequencies of the soil depend on the soil condition, chisel operating depth, and speed of operation. An increase in travel speed reduced the fracture distance. Increasing the operating depth of the chisel in the untilled soil eliminated one fracture mode.

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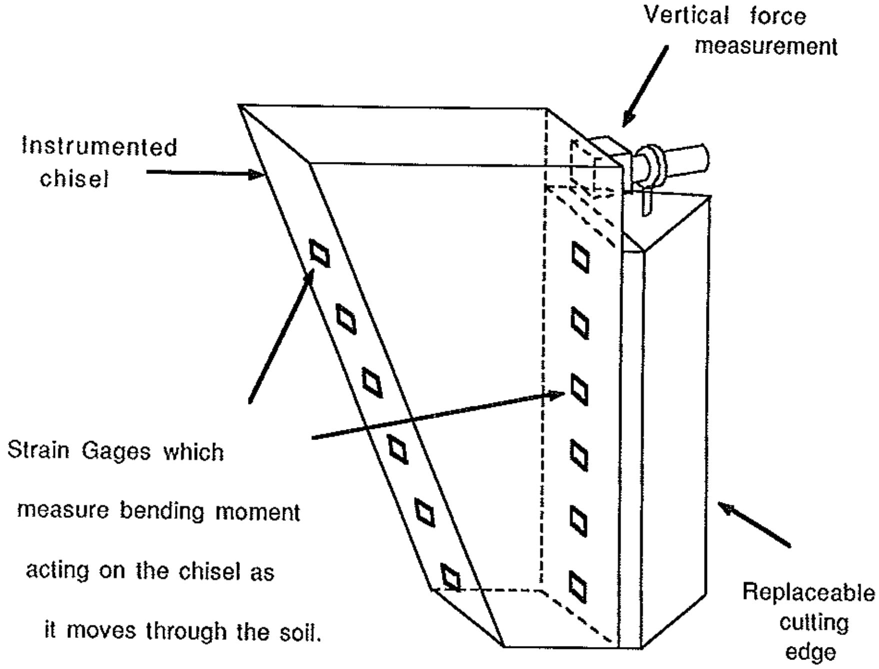

Figure 1. A schematic view of the chisel that has been developed.

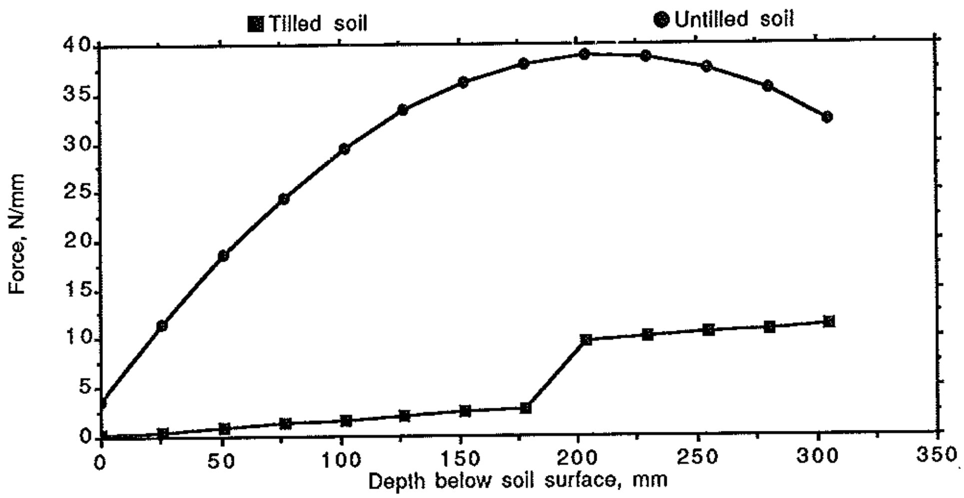

Figure 2. Force distribution acting on the chisel while operating at a speed of 3.2 km/h and a chisel depth of 305 mm in the tilled and untilled soils.

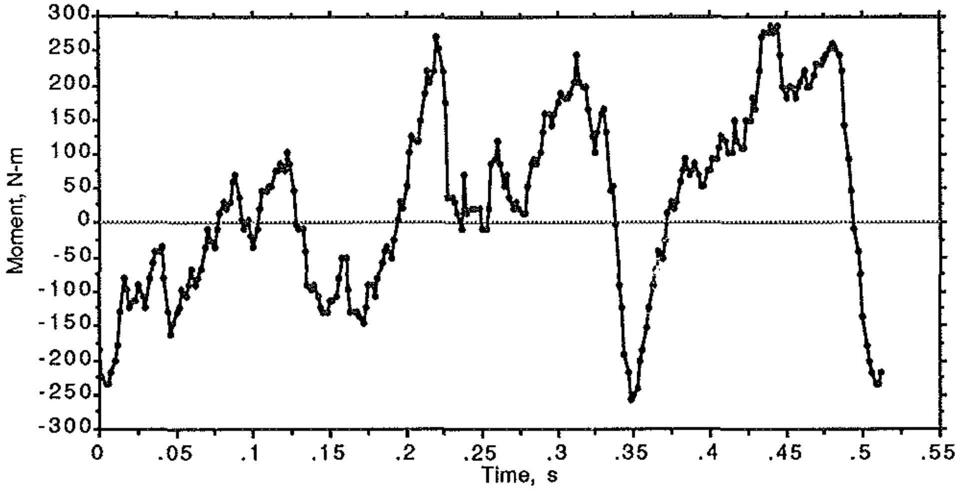

Figure 3. Variation in measured moment acting on the chisel in the untilled soil operating at a speed of 3.2 km/h and a chisel depth of 200 mm. The average moment was 1650 N-m and was subtracted off for the frequency analysis.

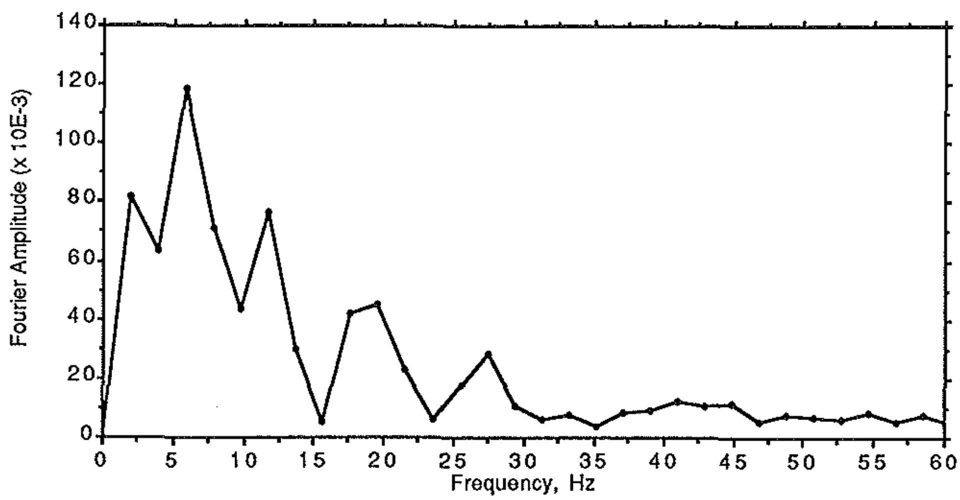

Figure 4. Fourier Transform results for the measured moment shown in Figure 3.

AN INVESTIGATION INTO THE PERFORMANCE OF FURROW PRESSES

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ABSTRACT

As part of the movement towards controlled trafficking and the reduction of compaction, considerable interest has been shown in drawing furrow presses directly behind mould board ploughs in varying soil conditions. This investigation considers the major design parameters influencing furrow press performance, measured in terms of soil compaction, soil disturbance and surface levelling.

INTRODUCTION

Furrow presses have recently been reintroduced after losing favour as a result of hitch arrangement difficulties encountered behind both mounted and reversible ploughs. There has, however, been little research evaluating the performance of the implement, but advantages claimed in their favour include:

i) consolidation of the furrow leading to improved moisture retention.

ii) breaking down and levelling of the soil, often enabling the drill to follow directly behind the plough.

iii) reducing the number of field operations to produce a seedbed.

This paper reviews part of the ongoing research at Silsoe College, aimed at investigating the factors influencing the performance of furrow presses, and considers the effects of implement geometry and weight.

IMPLEMENT GEOMETRY

From pilot field studies press geometry was found to be a major factor affecting soil disturbance. Subsequent investigations were undertaken to evaluate the effects of ring width, spacing and profile on press performance.

Ring width

The effects of varying ring width were studied in a glass-sided tank using sections of press rings lowered into a loose sandy loam soil, (Ansell 1986). The soil movement was monitored by introducing chalk layers.

The results obtained, figure 1, show the failure model developed by Ansell, which consists of three modes, dependent upon the working depth/width ratio (d/w) of the rings. These are: i) Narrow rings ($d/w > 2$) produce a predominently compressive failure with relatively low penetration resistance.
ii) Wide rings ($d/w < 2$) produce a classic foundation failure with relatively high penetration resistance.

iii) Medium rings ($d/w \approx 2$) develop a slip plane from the tip, with a compressive zone directly below. The penetration resistance lies between that of (i) and (ii).

Ring spacing

The effects of varying spacing between adjacent press rings were studied by Ansell using medium width ring sections. Four distinct failure mechanisms were identified, figure 2, dependent upon the spacing/width ratio. These consist of:

i) Independent passive failure zones (ratio $> 2.5:1$), with predominantly horizontal soil movement.

ii) Interactive failure (ratio $\cong 2.5:1$) with the passive slip planes coinciding, causing an increase in surface disturbance and penetration resistance.

iii) "Diamond failure" (ratio $\simeq 2:1$) where an active diamond shaped area can be identified, with the soil flowing around it and being deflected both upwards and downwards. This results in considerable surface disturbance and greatly increased penetration resistance.

v) Compressive failure (ratio $< 2:1$) where lateral movement of the soil is minimal, and the press simulates the action of a solid roller.

Full scale experiments were conducted under controlled soil bin conditions, using bead indicators to assess the resulting soil movement, (Sanchez-Giron Renedo 1985), (Dauda 1986). The results are shown in figure 3, and support the conclusions drawn from the experiments conducted in the glass-sided tank. These lead to the following observations:

i) wider rings are to be preferred in lighter soils as sinkage is reduced.

ii) the compressive action of narrow rings is beneficial in cloddy soils.

iii) spacing is critical, and will change the action of the implement. As the spacing/width ratio approaches 2:1 the press produces very weak surface conditions. Further reduction results in the press performing similarly to a roller.

Ring profile

The effect of various ring profiles on penetration resistance were evaluated in the glass-sided soil tank by Hagan. Sections of press-rings, all of the same width, but of varying profile were pushed into an uncompacted sandy loam soil. Results, figure 4, show that the penetration force increases with increased angle of approach but compound ring profile have little effect. Consequently, if reduced penetration is required, larger approach angles should be selected.

FURROW PRESS WEIGHT

Studies have been conducted to assess the effects of varying furrow press weight on implement performance by Hagan. Data was obtained using a modified cone penetrometer giving soil strength measurements in terms of plate sinkage. Figure 5 illustrates the effects of increasing press weight on the strength of a loose sandy loam soil under controlled soil bin conditions. The results show that an increase in weight has led to significant increases in strength at depth. However the strength of the top 50 mm of soil has been reduced, particularly at the higher ring weights. Results of field experiments conducted using the same range of ring weights on various soil types are shown in Table 1. These results support the findings from the soil bin studies for light textured soils, but indicate that reduced soil surface strength is not a problem in heavier textured soils at practical ring weights.

CONCLUSIONS

i) Press ring width/depth and spacing/width ratios have significant effects on the degree of penetration and disturbance produced.

ii) Ring approach angle has a significant effect on press penetration, with small angles leading to increased penetration. The use of compound profiles has no significant effect on performance.

iii) Increasing furrow press weight increases the penetration and compaction at depth. On light soils, there is a critical weight above which extreme surface loosening occurs.

ACKNOWLEDGEMENTS

The authors acknowledge the support in terms of finance and/or machinery of the Department of Trade and Industry and Hill & Osborne Ltd.

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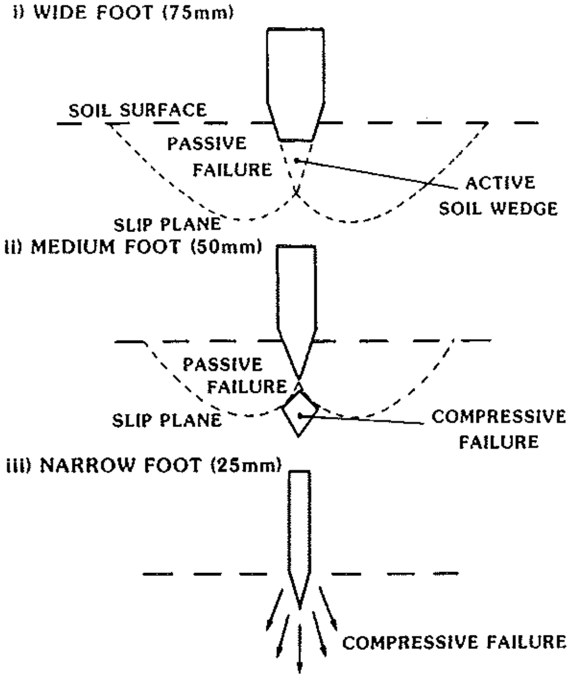

FIG 1 SOIL FAILURE MECHANISM BENEATH PRESS RINGS OF VARYING WIDTHS. (AFTER ANSELL 86)

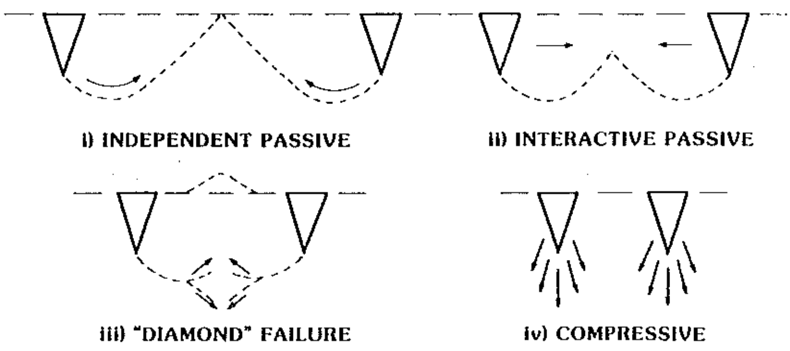

FIG 2 SOIL FAILURE MECHANISM BENEATH PRESS RINGS AT VARYING SPACING. (AFTER ANSELL 86)

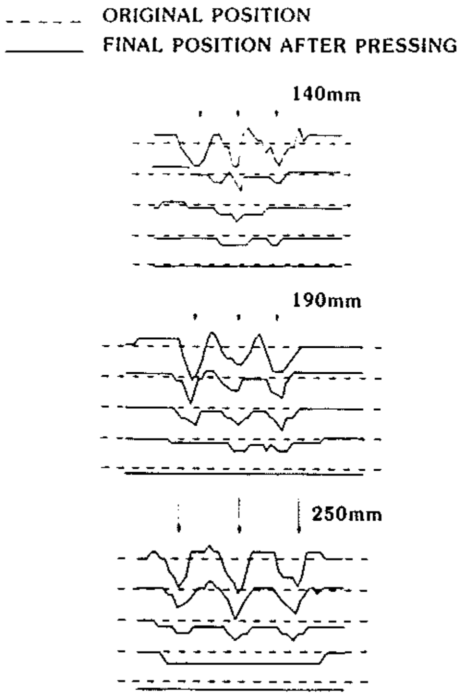

FIG 3 SOIL PROFILE MOVEMENT FOR VARIOUS RING SPACINGS MEASURED USING BEADS PLACED IN LAYERS AT 50mm DEPTH INTERVALS. (AFTER DAUDA 86)

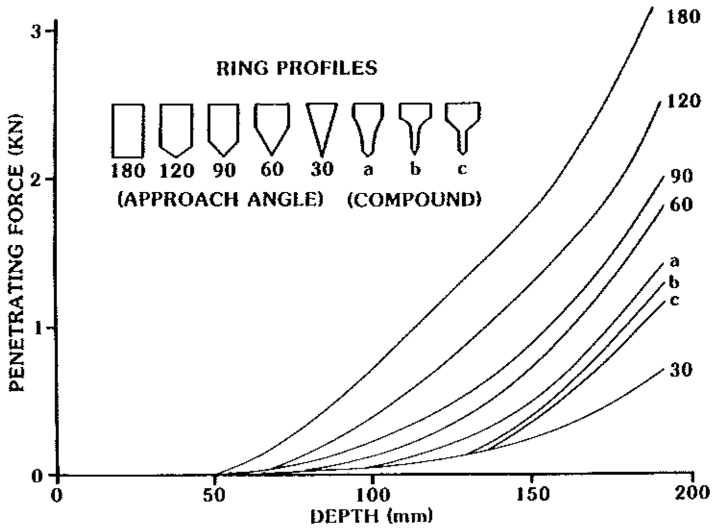

FIG 4 DEPTH / FORCE PENETRATION CURVES FOR VARIOUS APPROACH ANGLES. (AFTER HAGEN 87)

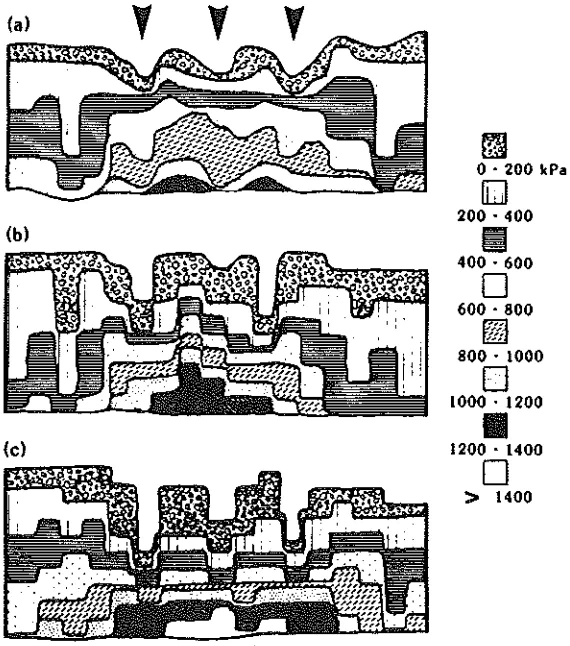

FIG 5 THE EFFECTS OF VARYING WEIGHT ON SOIL STRENGTH DISTRIBUTION (MEASURED IN TERMS OF PLATE SINKAGE) FOR ONE PASS THROUGH UNCOMPACTED SANDY LOAM SOIL WITH PRESSES OF (a) 86 (b) 112 AND (c) 138 Kg PER RING.

	Percentage Sinkage	
Weight per ring (kg)	Sandy Loam	Clay Loam
86	3.55	5.63
112	2.87	4.45
138	12.18	3.39

Table 1: The change in soil strength with increasing furrow press weight measured as percentage sinkage of a tractor wheeling.
(after Hagan 1987)

THE EFFECT OF STRESS DURATION ON THE PRESSURE TRANSMISSION IN AN AMELIORATED RED-BROWN EARTH UNDER IRRIGATION

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ABSTRACT

Soil stress measurements were made in a transitional red-brown earth (Typic Paleustalf) during one pass of a heavily loade (4 t) wheel. Different speeds (up to about 8 km h^{-1}) and soil water contents (close to the lower plastic limit) were used for measurements of total stress, final bulk density, air permeability and rut depth. Results indicated that effective stresses always seemed to decrease with speed. Increases of total stress by extra fluid pressure (i.e., pore water pressure) at 20 cm depth seemed to be associated with fast deformation rates of the soil (up to about 3 m s^{-1}) just under the leading edge of the tyre contact area. Shear stress changed very little with speed. Equations relating speed and water content to rut depth and resultant bulk density were also found.

INTRODUCTION

Mechanical compression of soils by agricultural vehicles is still the subject of much discussion and research. However, most laboratory research has used relatively long periods of stress application and slow deformation rates, which are often the most convenient for laboratory equipment, but only associated with very slow vehicle speeds. Drescher and Horn (1988) have summarized the current status of research, and clearly demonstrated the poor understanding of the influence of the variation of vehicle speed on soil compaction. Dexter and Tanner (1974) and Scholefield (1986) have described some of the fundamental responses of density and porosity of soils to stresses of short duration and fast rates of soil deformation, respectively, in laboratory experiments.

Few direct measurements have been made to clarify the influence of speed on the soil stresses under wheels running over soil in the field. Recently, Horn et al. (1987) described some in situ measurements of pressure transmission under tractor tyres. Short-period, repeated loading led to more intensive compaction and development of a plow pan.

Most measurements of stresses under wheels (e.g., Blackwell and Soane, 1978) have used conveniently low speeds (approximately 1 km h^{-1}). To investigate more common speeds used in agriculture, we used a field experiment with a range of forward speeds up to 8 km h^{-1} and measured the soil stresses.

MATERIALS AND METHODS

The soil is a transitional red-brown earth (Typic Paleustalf), ameliorated by deep ploughing to 30 cm and application of gypsum in 1983. The texture of the A-horizon was sandy clayey loam, while the B-horizon consists of sandy clay. The bulk density is 1.22 and 1.46 g/cm³ respectively.
After the last cultivation, the soil was spray irrigated with 80 mm of water at 50 mm h^{-1} by a lateral- move irrigator, and covered with polythene sheet to allow redistriution of water.
Each wheeling was on a different plot at water contents of the ameliorated soil just below or above the Casagrande lower plastic limit (21 % w/w); a suction between 6 and 12 kPa.
Three different kinds of speed were used, slow (approximately 0.7 km h^{-1}), fast (approximately 4.5 km h^{-1}) and very fast (approximately 8 km h^{-1}).
Forward speed and wheel slippage were calculated from measurements of distance and time. The wheeling was one pass by a single rear wheel of a 100 kW tractor with an 18.4-38 size water ballasted tyre, an inflation pressure of 140 kPa and contact area of 3,600 cm². Approximately 40 % of the whole contact area were tyre lugs, which were partly worn, with a height of 2-3 cm. In each plot stress transducers were installed at 20 and 35 cm depths, laterally from the sides of trenches dug alongside the plots. After the transducer was inserted, the hole was firmly back-filled with soil. The tranducers (Horn, 1980) measured vertical stress (σ_v), or horizontal stress (σ_h) with at least two replicates at each depth.
During wheeling, the signals from the transducers were recorded simultaneously each 0.1 sec by a field data logger.
The stresses were calculated by applying individual calibration curves for each transducer.
Water contents at 20 cm depth after wheeling were also measured. Bulk density and air permeability after wheeling were measured at 20 cm with soil cores cut in metal rings 100 mm diameter.

RESULTS

Stresses

No significant wheel slip was measured for any of the speeds or water contents, therefore we assumed there was no major contribution to soil stresses from shear forces at the tyre/soil interface. Especially at 20 cm depth, the measured stresses were sometimes even greater than the calculated mean contact pressure, while at 35 cm depth, 20 % of the contact pressure was registered. Furthermore, in the topsoil because of the lug effect, the variation between the values in the same depth is extremely high, again reducing with depth. The latter effect is further enhanced by the undisturbed soil structure in the B-horizon.

In Fig. 1, the mean vertical stress at 20 cm depth is shown for three speeds. At the slowest speed, the stresses lasted longer and the shape of the graph resembled a "flattened" sine wave. With increasing speed, the rate of increase of stress became faster and the duration of loading was shorter. In Fig. 2, the maximum values for σ_v, σ_h are shown in relation to speed. $\sigma_{v\ max}$ changed very little with speed at 20 cm depth. It seems to be, that at a water content above the LPL, increasing the speed resulted in higher $\sigma_{v\ max}$, while at a lower water content $\sigma_{v\ max}$ was less at the higher speeds. At 35 cm depth, an increase in speed resulted in a decrease of $\sigma_{v\ max}$. This decrease with speed also occurred for the σ_h values at 20 cm.
Figure 3 shows the change of σ_h/σ_v with time for three different speeds. If the wheel was exactly on top of the sensors, then the ratio was always at a minimum (< 1) (i.e., large shear stress). A maximum ratio (> 1) also occurred and could also be associated with large shear stresses. Forward speed had little influence on minimum or maximum ratio.

Rut depth

Wheeling caused considerable surface soil deformation and the formation of ruts. The mean rut depth increased with initial gravimetric water content (Θg) at 20 cm depth, and decreased with speed. Expressing the mean rut depth (mrd) as a logarithm, we obtained the following Eqn (1).

log mrd (cm) = 0.0485 Θg (% w/w) - 0.0046 speed (km h^{-1}) - 0.1089 (1) $r^2 = 0.817$ P = 0.004

Physical properties

Measurements of bulk density and air permeability at 20 cm depth before and after wheeling showed that with increasing speed air permeability increased and bulk density decreased. Additionally, especially in wet soils, the pore continuity is reduced (slightly higher K_a values of soil samples taken in horizontal direction compared with those taken in vertical direction).

DISCUSSION

The vertical stress measurements at 20 cm depth were considerably influenced by the tyre lugs. Measured values of up to 300 % more than the contact pressure can be explained if we assume that only 80 % of the area of the lugs is actually transmitting the load, because they were worn. Such high stresses measured in the same depth, have also been found by Horn et al. (1987) and associated with the effects of tyre wall stiffness on stress transmission. The variability at 35 cm depth may have been partly due to the influence of the lugs, but it may also have been the influence of the stronger and larger soil peds of the clayey B horizon which can make the stress transmission more heterogenous than in homogenous surface layers (Horn, 1983).
The most significant aspect of this experiment is the evidence for different processes of stress development in the weak topsoil and the strong subsoil. In the topsoil, total vertical stress tended to increase with speed, especially at

the higher water contents, but the resulting bulk density decreased with speed. It is unlikely that the decrease of density with speed is explained by changes of shear stresses, because shear stresses changed very little with speed. The results can be explained by pore water pressure changing the effective stress. Deformation of soil at high water contents is very sensitive to water movement, especially in the early stages of loading (Terzaghi and Jelinek, 1954). At early stages stress can be transmitted to the pore water pressure until the excess pressure can be relieved by water movement. This explains the large total stress at high speeds (at 20cm) and the tendency for larger total stresses in the wetter soil at the highest speed.

In contrast to the weak topsoil, the maximum vertical stresses declined as speed increased for the strong subsoil. Stresses had to be transmitted through the topsoil before they reached the subsoil. Thus, the longer periods of stress application at the slower speeds allowed a greater opportunity for subsoil stress to reach a maximum value. Hence, increasing speed resulted in lower maximum vertical stress in the subsoil.

Because soil compaction is a time dependent process, increasing speed resulted in decreasing increments of bulk density values. Thus, assuming no shear forces, no elasticity and no water saturation of the soil, faster forward speeds of a tractor e.g. should minimize damage to the structure.

However two major effects have to be considered, too. Due to a certain elasticity, platy structure will be formed even due to a single short time loading, resulting in a reduced pore continuity. Thus, water or gas permeability are reduced even at the same bulk density, too. Furthermore, the complete disturbance of soil structure by repeated wheeling due to kneading should also beconsidered, especially if the water saturation is high or if even excess water is available. Horn (1978) measured such changes as a result of kneading wet soil.

CONCLUSIONS

(1) Effective stresses in this subsoil (35 cm) declined in magnitude and duration as speed increased to about 8 km h^{-1}.

(2) Total stresses at 20 cm depth in this topsoil, near saturation, increased with speed. This seemed to be due to large pore water pressures associated with the faster rate of soil deformation under the leading edge of the contact patch at higher speeds (up to about 3 m s^{-1}).

(3) Shear stresses changed little as speed increased.

(4) Mean rut depth and bulk density at 20 cm could be diminished by about 10 % by increases of speed from 0.5 to 10 km h^{-1} for this soil at water contents near the lower plastic limit. This may be applied to the risks of soil damage by heavy vehicles over such fine textured soils at high water contents.

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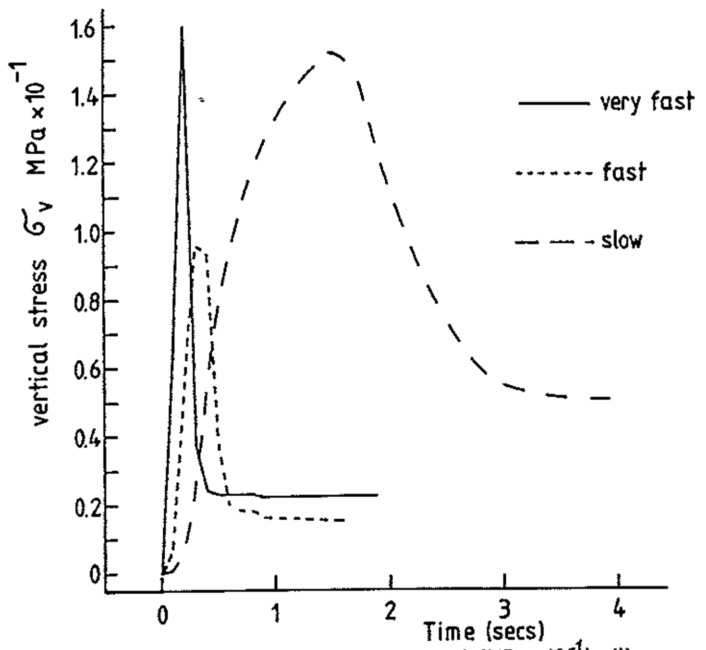

Fig. 1: Changes of vertical stresses σ_v (MPa $\times 10^{-1}$) with time for 3 kinds of speed (water content ~20% by weight).

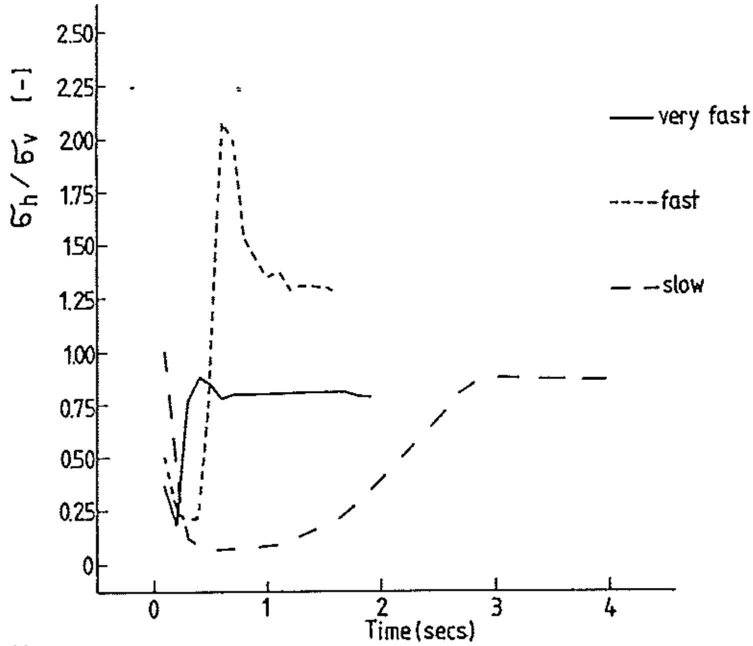

Fig.3: Variation of σ_h/σ_v ratio with speed at a depth of 20 cm. water content ~ 20% (by weight).

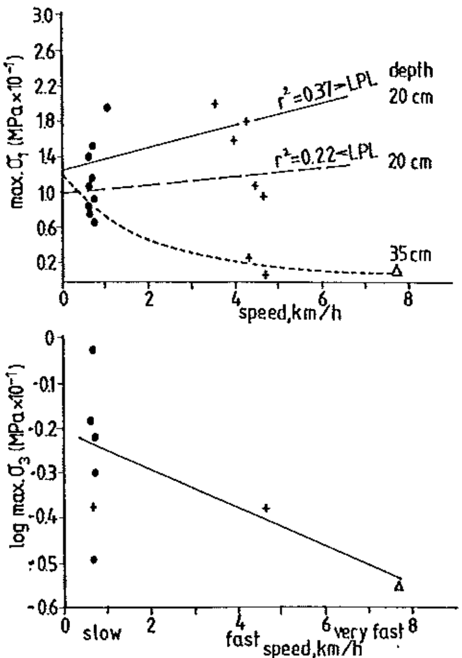

Fig.2: Changes of mean vertical and horizontal stress with speed.

EFFECT OF SUBSOILING ON PHYSICAL PROPERTIES AND CROP GROWTH ON A SANDY SOIL WITH A NATURALLY COMPACT SUBSOIL

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ABSTRACT

A Subsoiling trial was carried out during 1984/85 on a soil with a sand texture and naturally compact subsoil. Root growth of the subsequent crop (Spring oats var. Maris Tabbard) was not restricted by water logging or water stress, and profile pH and supply of major and minor nutrients were not limiting. Rooting depth and density were improved and there was a 19% increase in crop yield on the subsoiled plots. A new method of penetrometer data presentation accounted for 58% of the variance in subsoil rooting density. By the end of the first growing season, subsoil dry bulk density had returned to its original value before subsoiling but the reduction in penetrometer resistance persisted.

INTRODUCTION

The experimental site was located approximately four kilometres to the East of Tain in the Dornoch Firth area (National grid reference: NH816816). The field in question had a history of unsatisfactory yields which could not be attributed to crop nutritional or disease problems. A detailed soil survey of the site showed the presence of a compact sandy subsoil which restricted rooting depth. Over most of the site this was due to a naturally cemented and podzolised B horizon, but even in areas where this horizon was absent the sandy subsoil exhibited a high penetration resistance which also impeded root growth.

The aims of the experiment were to establish whether physical impedance was responsible for the poor crop growth, to examine the effects of subsoiling on the physical properties of the soil and to establish whether any beneficial effects of subsoiling would persist. This experiment is described in more detail in Jamieson (1987) and Jamieson et al. (1988).

MATERIALS AND METHODS

A Subsoiling trial (using a single tined subsoiler) was carried out during 1984/185 on a light textured sandy soil (Links and Nigg soil associations developed on wind blown and raised beach sands). Spring Oats (var. Maris Tabbard) were sown in March 1985 and subsequent crop and soil physical properties were measure from the six (3.5 x 3.5 m) microplots established within each of the subsoiled and control treatments. A stratified random sampling design was adopted to encompass the pattern of microdunes and dune slacks running at right angles to the treatments. As far as possible the crop was grown under optimum nutrient conditions so that these factors would not exert a major influence on root growth and crop yield. Piezometers and tensiometers were used to monitor the water table and a rain gauge measured rainfall on site. Dry bulk density was measured using twelve replicate 100 cm^3 undisturbed cores prior to subsoiling and throughout the growing season on both treatments. Penetrometer measurements in a part of each microplot were carried out on six occasions during the growing season. Penetrometer measurements were also made along transverse and longitudinal transects across the whole of the trial area. A "Bush" recording penetrometer was used (Anderson et al., 1980). Grain yield was measured from each microplot and in addition root counts were carried out at two locations per treatment directly adjacent to four of the microplots immediately after harvest.

RESULTS

In the subsoiled treatment there was a significant drop ($P < 0.001$) in subsoil dry bulk density from 1.34 Mg m^{-3}, prior to subsoiling, to 1.16 Mg m^{-3} following the soil loosening operation. However, subsoil bulk density was found to increase progressively and had regained its original value of 1.34 Mg m^{-3} after harvest.

Because penetrometer resistance varied little with time during the growing season, results for each microplot were pooled to represent the time averaged resistance experienced by the roots during the growing season. Figure 1 shows results for two of the microplots. Following the treatment of Groenevelt et al. (1984) summation curves are given which represent the number of readings at each depth (out of a total of 60) with penetration resistances of less than 3.0, 2.3, 1.9, 1.1 and 0.4 MPa. These represent a range of values from 3 MPa at which point the relative growth rate of roots is virtually zero, through values of 2.3 to 1.1 MPa which will exert a considerable constraint on root growth rate, to 0.4 MPa which should have little effect on roots (Graecen et al., 1969). Although the dry bulk density returned to its original undesturbed value, a comparison between penetrometer readings just after subsoiling with those taken on the same treatment after harvest showed that there was little if any increase in penetration resistance whereas the contrast between the two treatments remained (Figure 1). Figure 2 shows that there was a concentration of roots near to the surface (within the top 20 cm) and a dramatic decrease in the rooting density between 20 and 25 cm depth in the control microplot (C1). In comparison there was a more gradual decrease in rooting density throughout the soil profile in the subsoiled microplot (S1). A regression of rooting density from four microplots, Y (cm^{-2}) on the number of penetrometer readings less than 1.1 MPa, X gave the following result for the subsoil (27 to 51 cm) zone:

$$Y = 0.012 + 0.019X \qquad r = 0.76^{**} \ (P > 0.01)$$

The average yield of the microplots located in the subsoiled area was 4.92 t ha^{-1} which was significantly greater ($P < 0.05$) than the yield of 3.91 t ha^{-1} from the control microplots.

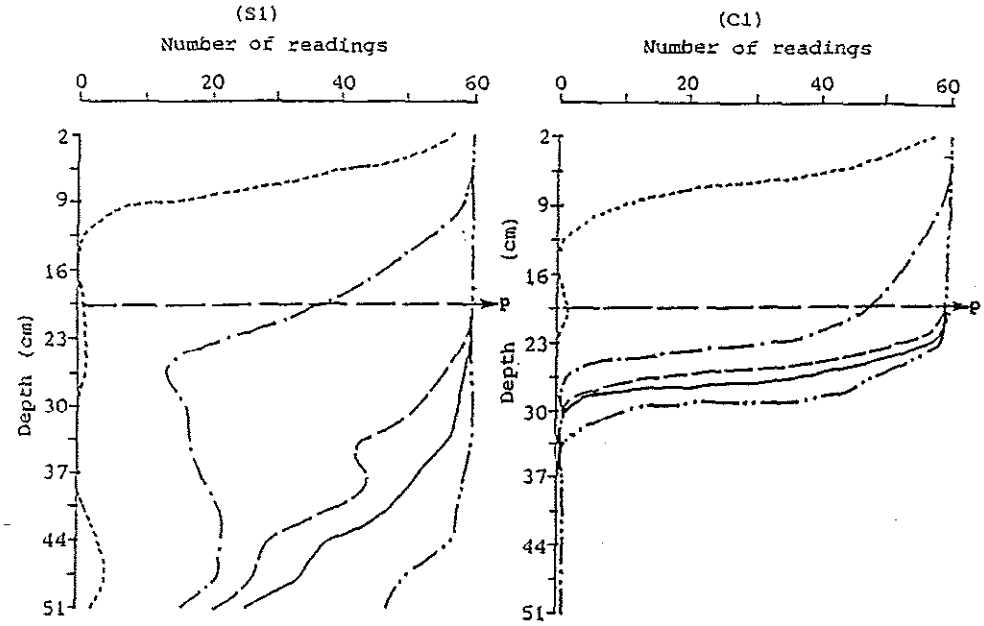

Figure 1 Pooled number of penetrometer readings less than 3.0 (—··—·), 2.3 (——), 1.9 (— — —), 1.1 (—·—·) and 0.4 (-----) MPa versus depth for microplots S1 (subsoiled) and C1 (control). P indicates depth of ploughing.

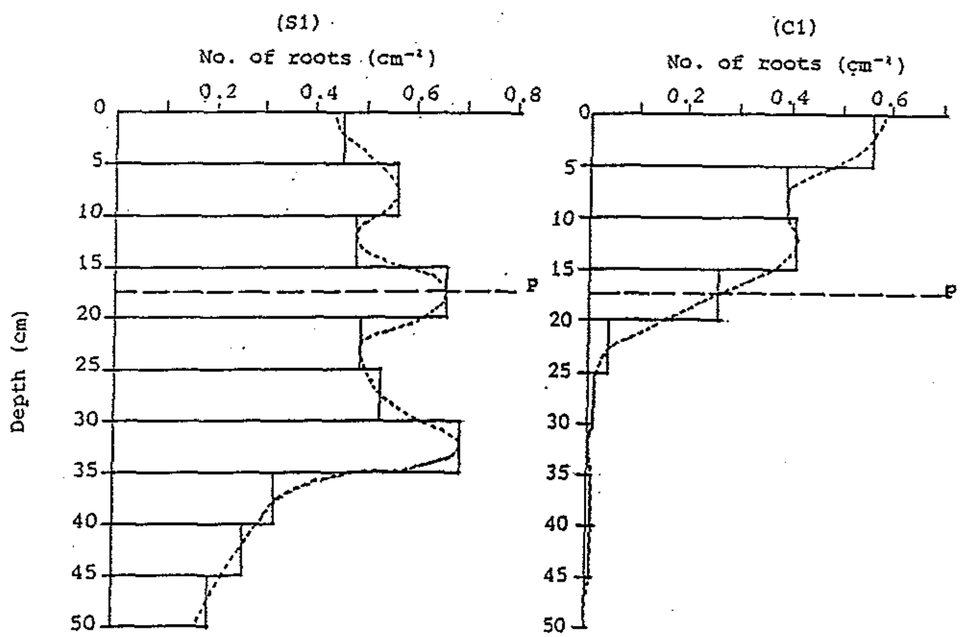

Figure 2 Rooting density versus depth for microplots S1 (subsoiled) and C1 (control). P indicates depth of ploughing.

DISCUSSION

Lime and fertiliser levels (for N, P, K, S, Cu) were based on detailed soil analysis. These and subsequent subsoil pH measurements showed that there were no major chemical limitations to crop and root growth. In addition regular monitoring of the crop throughout the growing season showed no sign of irregular growth or disease.

The moisture release characteristics in conjunction with meterological data showed that at no time was the crop under moisture stress. Similarly piezometer and tensiometer measurements indicated that the regional ground water table during the growing season was not high enough (> 1 m depth) to restrict root growth nor was there any perched water table. It was therefore concluded that any differences between the two treatments could be attributed to soil physical conditions and in particular penetration resistance. The increase in dry bulk density showed that after subsoiling the soil started to repack but the penetrometer resistance results suggest that the reduction in soil strength remained. Therefore, although the soil repacked the natural cementation in the soils with a podzolised subsoil was disrupted and may remain so for some years to come.

CONCLUSIONS

1. Adverse pH, waterlogging, water stress and major nutrient or trace element deficiencies were not limiting factors to root or crop growth during the 1985 growing season.

2. Rooting depth and density were improved in the subsoiled microplots.

3. Where the subsoil had been loosened there was a 19% increase in crop yield.

4. A new method of presenting penetrometer data accounted for 58% of the variance in subsoil rooting density.

5. At the end of the first growing season subsoil dry bulk density in the subsoiled treatment had returned to its original value but the reduction in penetrometer resistance persisted.

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CHISEL PLOUGH AND THE PRIMARY TILLAGE IN HUNGARY

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The large and heavy agricultural machines, with their growing numbers and traffic, cause extensive soil compaction which interferes with profitable crop production. Chisel ploughs /medium deep looseners/ have been found to be good instruments to counteract the undesirable consequences in that they facilitate the improvement of water, air and nutritive management in soils by operating at a depth of 250-500 mm. Our latest field tests were aimed at defining the dimensions /width and rake angle/ of tillage tools of widely used machines that can be used with the best effect on medium heavy soils.

INTRODUCTION

The heavy traffic of tractors and tillage equipment, with their ever increasing dimensions and weights, the excessive use of disk harrows, which are notorious their compacting effect and a practically impenetrable layer generated by the repetitive primary tillage /plowing/ at approximately the same depths contribute to the deterioration of soil compaction. So, one can speak of compacted surface /subsurface/ layers and compacted layers at the bottom of cultivation /subsoil/.

The compacting of soil can be eliminated by loosening. Therefore we have to develop and introduce tillage implements and methods which can be effectively used in combination with the great numbers of the four-wheeled tractors of the large-scale farms. The method to be proposed in medium deep loosening with a depth of 250-500 mm for which the implements and the machines been selected in the course of experiments and tests conducted in recent years. Production of medium deep looseners of the RÁBA-IH-10-14 family was begun on the basis of the results of field tests with various designs of medium-deep looseners such as IH-14, LATAR-2500, Haylock Triple Task, Howard-Paraplow, Howard Rotadigger. Implements, manufactured under an IH licence, are made in 3-9-leg versions subject to soil type and tractor size, with three different leg spacings /508/635/762 mm/ depend on working depths. However, the working elements /shears/ of the medium deep looseners are same, although different solutions would be required by the varying operating conditions.

METHOD AND RESULTS

Considering the above, the objective our latest experiment was to develop a series of implements, whose field tests may help us select the most effective geometrical dimensions.

The working elements developed for the purposes of the experiment were mounted on the middle leg of a RÁBA-IH-14-5 mounted medium-deep loosener.

In case of shears, or those wing type ones the working elements were replaceable, while in the case of wings welded to the leg, the leg itself was replaceable.

The markings of the various working elements and their most important data are given in Table I.

The various working elements were tested with the same frames at three speeds.

The field tests of the tillage implements were conducted by using FIAT-1880 DT tractors on a grain stubble with sandy loam soil of the Balatonszárszó "Vörös Csillag" Agricultural Cooperative. At the time of the tests the moisture content of the soil and its dry bulk density was 12.5-14.8 % and 1.49-1.69 $g.cm^{-3}$ at a depth of 25-30 cm, and 15.1-16.3 % and 1.41-1.65 $g.cm^{-3}$ at a depth of 45-50 cm, respectively.

When testing the tillage implements, we were trying to find answers to the following questions:

What is the impact of a change
- in the rake angle /20-35^{o}/
- in the width of the working element /60-300 mm/
- in the height of the wings on leg /0 or 200 mm/

on work quality and energy consumption.

Based on the field test results and experiences, we have found that

- on medium heavy soils rake angles of 25-30^{o} are favourable, based on the size of cross section of soil disturbed, loosening effect defined by the rise in surface level and the energy requirement;
  - an increase in rake angle would result in greater cross sections only within a certain range;
  - the increase in the rake angle would increase the draught force and the power required;
  - energy features prorated to the width of the cross section were the most favourable in the middle angle range /25-30^{o}/;
- as regards the change in the width of the working element, increasing the width of the wing mounted on the shear is more favourable than that of the shear;

- on the basis of the combined evaluation of the energy features and work quality characteristics /cross section, rise in surface level/, the 200 mm wing width is to be considered the most favourable;
- the size of area loosed by the wings mounted on the shears /to be calculated from the dimensions of the cross section/ substantially exceeds that of the simple shears;
- the energy requirement per working width of tools with wings is significantly lower than that of traditional shears /the difference in respect of specific draught force is 25-40 %;/
- from the point of view of wings arrangement, the shear mounted solution is the most favourable;
  - wings mounted on shears can make a cross section 30-50 % greater than that wings mounted at a height of 200 mm on leg;
  - from the point of view of specific energy features, lower mounted solution is more favourable, probably as a result of the better shear-to-wing arrangement.

CONCLUSIONS

To sum up the results and the experiences of the tests we can state that in an environment with conditions similar to those of the experiment, ie. on medium heavy soils, the 25-30° rake angle range and the 200-300 mm wide wings, mounted on shears, are the most favourable. By using the selected technical parameters in practice, the tillage efficiency of the medium deep looseners can be improved, while their energy consumption can be reduced.

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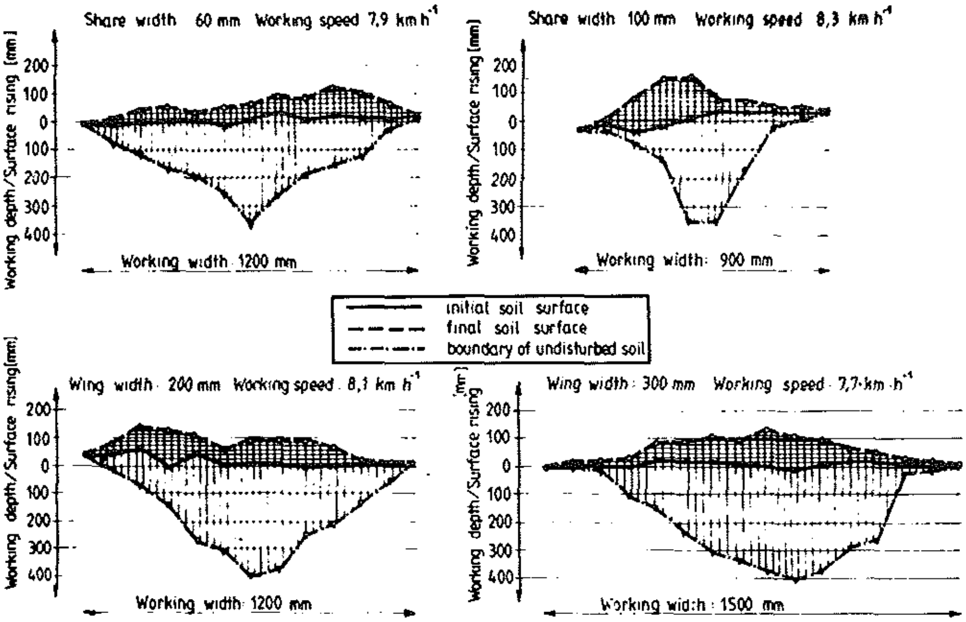
The data of working elements

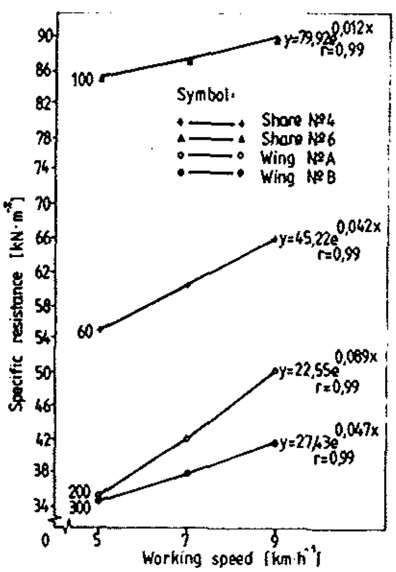
Table I.

Tool mark	Rake angle /degree/	Width of shear or wing /mm/
2	20	60
3	25	60
4	30	60
5	35	60
6	30	100
A	30	200
B	30	300
C	30	200
D	30	300

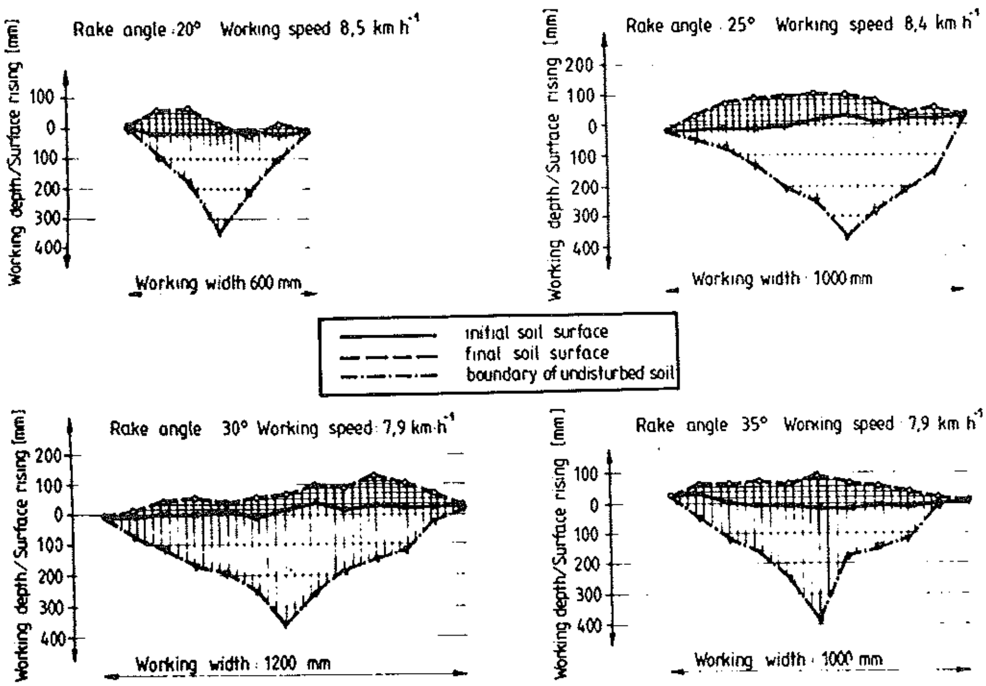
Cross section of different share (wing) widths (60 - 300 mm)
Rake angle 30°



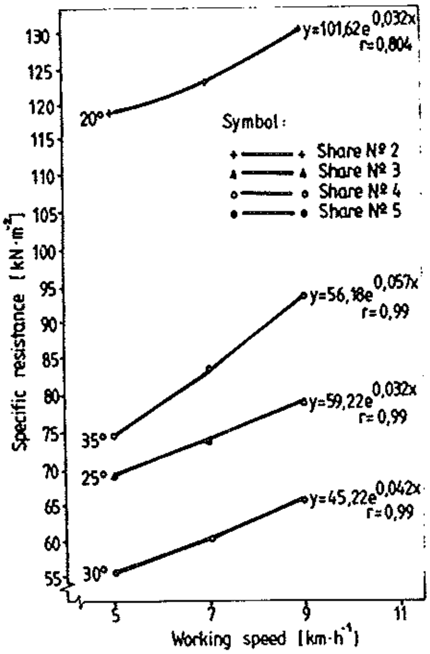
Specific resistance with different share (wing) widths (60 - 300 mm)
Rake angle: 30°



Cross section of different rake angle (20-35°)
Share width 60 mm



Specific resistance with different rake angle (20-35°)
Share width: 60 mm



EXPERIMENTAL STUDY ON THE SOIL FLOW AND PERFORMANCE RELATIONSHIP FOR ELEMENTS OF DIFFERENT RUNNING DEVICES

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ABSTRACT

A specially designed set of equipment including soil box, model elements of different running devices(lugs of powered wheel, floating bodies, screws), motored camera, dynamical strain amplifier and recorder, and microprocessor is used to study the soil flow and performance relationship for those elements. The purpose of this study is to predict the dynamical forces ofthese elements in sand, in clay and in paddy soil on the basis of actual soil failure pattern beneath them, and to obtain the optimum design and improvement for them. Thousands of photographs on soil flow of different elements and many rolls of tape-record on forces had been taken, and the empirical formulas of performance are derived based on the dimensional analysis,similitude and statistical analysis.

INTRODUCTION

In order to reach a better understanding of vehicle-soil interaction, it is necessary to have experimental study into actual soil flow and soil reaction beneath moving elements of running devices. It is considered that the knowledge of the actual soil flow beneath these elements and soil reaction will give a better understanding to mechanics and performance for them and will lead to a sound theoretical basis for the prediction on their performance and for the improvement of their design.

Four research projects were carried out during 1983-1986 at the Department of Agricultural Engineering, South China Agricultural University.The purpose of these projects was to study the soil flow beneath different elements of running devices and their correspondent dynamical performance and their relationship and to improve their design. Three elements were selected: lug, boat, and screw. The lug of a rigid wheel or a pneumatic tire is the basic element to interact with soil; the sliding boat is the main element tofloat on paddy soil; and the rotor screw is a propelling element on boat-screw vehicle in paddyfield.

We observed the soil flow and measured the soil reaction simultaneously so that both the soil failure patterns and the correspondent forces of these elements were obtained.

These experiments were the continuous research which had been conducted on soil flow beneath wheel lug at Transport Technology Research Laboratory in Carleton University Canada with Professor Wong Jo-yung and Mr. Wu S.X. and Mr. Hu J.H. in 1983. [1] [2]

Since Hettiaratchi and Reece developed the calcuation of passive soil resistance in 1966.[3] During experiments conducted by Gee-Clough and Chancellor 1976 [4] , Zhang and Shao 1984 [5],Dengand Youg 1984 [6], the prediction of lug forces by this theory were found to be in good agreement with the experimental results. Salokhe, Gee-Clough and Rajaram found soil wedge in ellyptical shape at 50% slip on lug face beneath wet paddy soil and declared that the existing theory could not be used to calculate the forces, in 1987. [7] [8]

The Chinese developed boat-wheel vehicle are broadly used in deep and soft paddy field districts of China. The boat-wheel vehicle is a kind of speceal vehicle equipped with boat and lug wheels. The boat body is used as floating and bearing device with very low contact pressure (2 - 8 kpa) and low sliding resistance on paddyfield. The wheel is used to develop propelling force and to create enough drawbar pull for farm work.

The soil flow beneath bottom of sliding body in paddy soil with or without water film and the correspondent sliding resistance were studied.[11]

The boat-screw vehicle had been developed for paddy field use since early 80's in China. This vehicle had a floating boat and four rotor screws in which the screws were used as propelling devices.

A preliminary study into soil flow beneath screw in sand and clay slurry and the correspondent soil reaction was carried out.[10]

APPARATUS AND PROCEDURE

All the experiments were conducted in a 1200x600x125mm glass sided box for model lugs and model boats, and in a 2000x800x600mm glass sided box for the model screws, as shown in photographs at poster presentation.

The model wheel 390mm in top diameter with a circular disc 220mm in diameter and 6mm thickness in which a lot of holes for securing lugs with different angle and octagonal sensors.was used for experiments.

The model boat was 1:13 on the reduction scale with the actual boat of boat tractor. The model screws were with 75mm rotor, 125-155mm top diameter, 30^o screw angle and different length in 136,272,408mm.

All the model elements were drive by an engine lathe and various slips were obtained by altering the feed of apron and the lathe gear ratio.

The soil flow photographs were taken by a motored camera besides the glass while the elements were rotating or moving in box. The soil reaction such as thrust,bearing force and torque was recorded simultanously by dynamical strain amplifier and magnetic tape recorder. All the datum from experiments were put into microprocessor and plotter for analysis and processing.

In experiments, the dry sand, wet clay and wet paddy field soil in soil box with the following parameters are shown in Table 1.

Table 1 Soil parameters

Soil type	Unit weight (kN/m^3)	Cohesion (kpa)	Internal friction angle	Soil-metal friction angle	moisture content(%)
SAND	14.7	-	28^o	18.5^o	- -
CLAY	16.8	4	5^o	2.5^o	56
PADDY SOIL	17.2	2.5	13^o	10.0^o	37

SOIL FLOW BENEATH SINGLE LUG AND MULTI-LUG

Carefully studied thousands of photographs on soil flow beneath single lug and multi lug in pure dry sand , wet pure clay and paddy soil at various slip, various number of lug and different lug geometry(lug angle, height), we found soil flow of all experiments for dry sand similar to the existing passive soil pressure theory at all conditions, soil flow of most experiments for wet pure clay and paddy field soil also similar to the existing theory at slip from 15.2-35.2%. No wedge was found in dry sand. The soil wedges with top angle β and lower boundary circle were found in wet clay and paddy soil at 15.2-35.2% slip. When the slip was higher than 49.5%, the elliptical wedge was observed as illustrated in paper [7] [8].

The soil flow beneath single lug and 6 lugs in pure dry sand at 49.6% where transition zone and Rankine zone might be observed was shown in Fig. 1, but no wedge was found. The soil flow beneath single lug and 6 lugs in pure clay and 9 lugs, 12 lugs in paddy soil was shown in Fig. 2 and Fig. 3 where soil wedge, transition zone and Rankine zone might be observed. These figures were selected on lug positions where maximum soil deformations or reactions were developed.

The soil failure pattern beneath multi-lug in comparison with single lug was quite different. The obvious differences were: the incomplete Rankine zone, smaller in area, the preceeding cavity giving an interruption to the flow line of soil particles, and the angle between flow line and horizontal line being smaller than 45°-$\phi/2$, as illustrated in [1] and shown in figure 1 to 3. More information and photographs in complete set will be shown at poster presentation.

The failure pattern beneath lug in pure dry sand and wet pure clay in our experiments basically repeated their styles as the work at TTRL Carleton University. It was obvious that all failure patterns basically conformed to the theory and principle of soil mechanics although there might be some deviation or distortion.

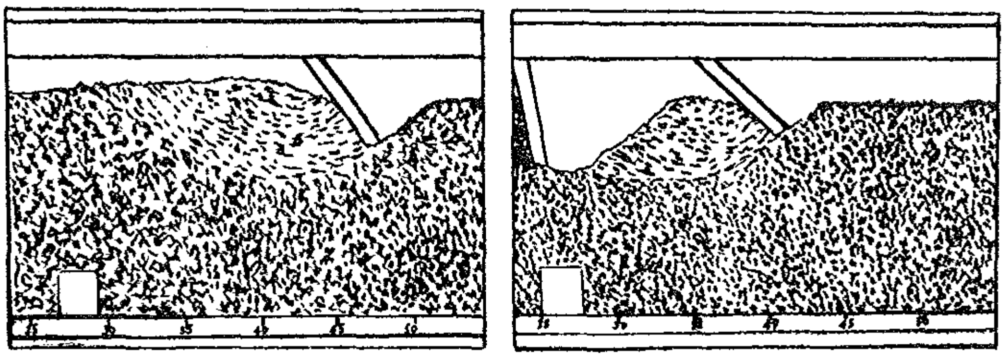

Fig. 1 Soil flow beneath single lug (left) and 6 lugs(right) in sand at 49.6% slip

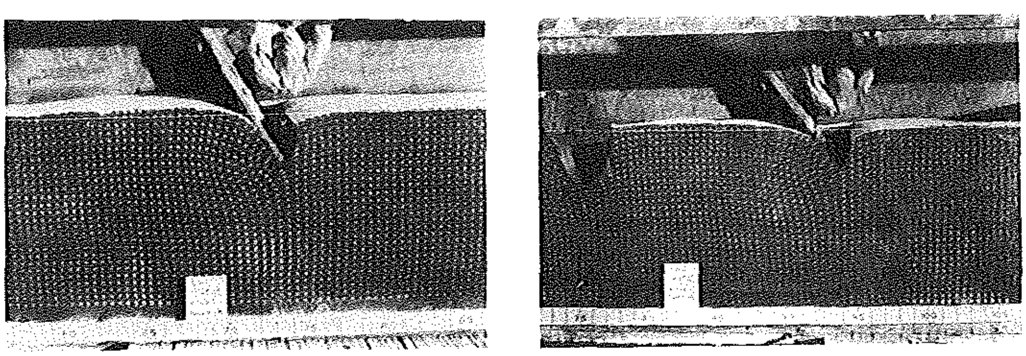

Fig. 2 Soil flow beneath single lug(left) and 6 lugs(right) in clay at 25.2% slip

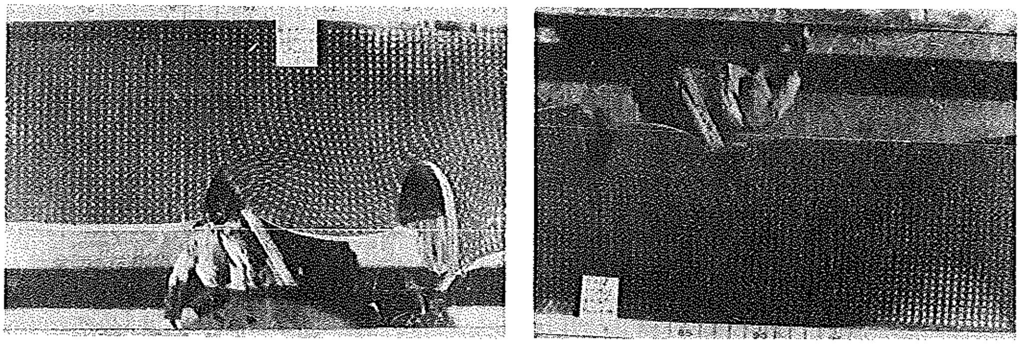

Fig. 3 Soil flow beneath 9 lugs(left) and 12 lugs(right) in paddy soil at 25.2% slip

STATISTICAL REGRESSION ON MEASURED SOIL REACTION BENEATH MULTI-LUG

On the basis of passive pressure theory in two dimensional failure pattern the equation of soil reaction on single lug had been developed. There was a satisfactory agreement between the measured results and predicted pull and lift forces on single lug as illustrated in paper [5].

The actual wheel is a multi-lug wheel. The soil flow and soil reaction beneath multi-lug will have deviation over single lug. It is clear that the measured soil reaction of multi-lug wheel is not a piling up of that on single lug, but less than that on single lug according to slip, number of lug, and geometry of lug, and the internal friction angle of soil. There exists a reduction factor 'interference' between lugs in soil reaction.

Two reduction factors K_1, K_2 were introduced, where $K_1 = F_{mp}/F_{sp}$, $K_2 = W_{mp}/W_{sp}$. F_{mp} and F_{sp} were the pulls of multi-lug and single lug respectively, W_{mp} and W_{sp} were the lift forces of multi-lug and single lug respectively, and the foot note p meaned paddy soil.

Based on the dimensional analysis and similitude, the general formula of the reduction factor of multi lug in paddy soil is:

$$K_1 , K_2 = f(i, \alpha , L/h, \phi)$$

The following empirical formulas for K_1 and K2 were derived by means of the regressive treatment of measured datum.

$$K_1 = 1.2858\ i^{-0.1626} (0.8495-0.001717\alpha)(0.64+0.0489L/h)(0.8495-0.01019\phi)$$

$$K_2 = 1.3559\ i^{-0.1647}(0.9027-0.004253\alpha)(0.571+0.06361L/h)(0.9641-0.01407\phi)$$

The correlation coefficient was 0.9030 for K_1 formula and 0.8847 for K2 formula. These two empirical formulas may be used to predict the pull and lift force of multi-lug wheel in paddy field if the reaction of single lug is measured and the slip i, the lug angle α, the distance between two adjacent lug L and height of lug h, and internal friction angle ϕ are known. [9]

SOIL FLOW BENEATH SLIDING BOAT ON PADDY SOIL WITH OR WITHOUT WATER FILM

In these experiments the sliding boat was dragged forward horizontally with a speed of 0.2m/s under a contact pressure of 5.7 kpa along surface of paddy soil.

The soil flow beneath sliding boat on wet paddy soil without water film was in higher moisture stress in I_3 and I_2 treatments as compared to I_1 . The results show that the traditional 7-day irrigation should be used.

CONCLUSIONS

(1) A dense tillage pan with an average bulk density of 1.70 g cm^{-3} has developed on this soil and is located at about 15 to 20 cm from the soil surface.

(2) Deep tillage effectively break the compacted pan resulting in 3 to 8 fold increase in infiltration rate, lower bulk density and improved grain yield.

(3) Effects of deep tillage on grain yield are transitory, and even subsoiling may not produce statistically significant yield increase for more than one year.

(4) A relative yield increase of more than 10 percent, over the conventional tillage, for two years is possible on this soil simply by deep tillage and chiselling to a depth of 25 to 30 cm is sufficient.

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Throughout the study period, irrigation frequency significantly affected grain yield at 1% level irrespective of tillage treatment and both means were statistically different (Table 1). The 7-day frequency consistently gave higher yields followed by the 14-day frequency. Interaction effects between irrigation and tillage were not significant.

Correlation Between Yield And Bulk Density:

A regression analysis between grain yield (Y) and the average bulk density (Bd) at 10 to 30 cm depth was carried out to investigate the effects of bulk density on grain yield. However, a very weak correlation was obtained (as given below) and the correlation coefficient, r, showed a decreasing pattern over the years.

1985 ; $Y = -4.67\ Bd + 12.05$, $r = 0.60$
1986 ; $Y = -6.22\ Bd + 12.83$, $r = 0.55$
1987 ; $Y = 1.35\ Bd + 0.61$, $r = 0.15$

DISCUSSIONS

The deep tillage was effective in loosening the dense tillage pan resulting in lower bulk density, higher infiltration rates and improved grain yield. However, there was a general decline in the soil physical properties over the three years which showed that the tillage pan had started reforming. This trend is more evident in the regression equation presented above. In 1985, deep tillage significantly affected bulk density and grain yield and the regression showed a slightly higher correlation coefficient (r=0.60). When tillage effects were not significant, the r value was slightly lower in 1986 and was worse by 1987. The long term effects of deep tillage on grain yield exhibited a declining trend. The effects were significant in the first year only and the relative yield increase progressively decrease with time especially in the case of subsoiling. These results are similar with those reported by Miller (1987) where he found that subsoiling significally increased dry bean yield only in the first year and the effects were not significant for the carry-over in the second and third years. Our work and those of Miller (1987) confirm the earlier report that changes in soil physical properties brought about by tillage to affect grain yield are often transitory (Duley, 1957). Although the yield differences in the subsequent years were found to be statistically non-significant, it is felt that a relative yield increase of 10 to 20 percent for two years, simply by deep tillage, is good enough but economical justification should be considered.

It was postulated that deep tillage would improve the water intake and soil water holding capacity, which should result in longer irrigation interval. However, no appreciable interaction effects were observed between tillage and irrigation and further more, the irrigation frequencies were found to be statistically different. This is explained by the fact that approximately equal amounts (45 mm) of water were applied to the treatments at each irrigation. This resulted

The compacted pan with an average bulk density of 1.71 g cm^{-3} was located at 15 to 20 cm below the surface in the conventional tillage . Subsoiling and chiselling reduced the bulk density in the compacted pan to 1.58 and 1.61 g cm^{-3} in the first year, respectively. However, in the second year, the bulk density was 1.61, 1.64 and 1.70 g cm^{-3} and in the third year, 1.64, 1.65 and 1.70 g cm^{-3} for subsoiling, chiselling and conventional tillage, respectively.

Grain Yield:

Deep tillage treatments significantly increased grain yield at 5% level for the first year only. The mean from conventional tillage statistically differed from the two deep tillage treatments (Table 1). In the subsequent years, the yields under both treatments were not significantly different. However, subsoiling exhibited higher relative yield increase (RYI, as defined in equation 1) of 24.4, 23.4 and 14.9 percent for the first, second and third years respectively while chiselling gave RYI of 17.3, 19.2 and 0.0 percent for the respective years.

$$RYI = \frac{Yd - Yc}{Yc} \times 100$$

Where RYI is the relative yield increase, Yd and Yc are mean yields from deep (Subsoilling + Chiselling)and conventional tillage treatments, respectively.

Table I. Effect of tillage and irrigation treatments on grain yield of wheat.

Treatment Tillage	Irrigation intervals (day)	Grain Yield (Mg ha^{-1}) 1985	1986	1987
Subsoiling	7	5.31	3.66	3.50
	14	4.68	2.58	3.07
	21	4.32	2.10	2.63
Chiselling	7	5.00	3.52	3.51
	14	4.76	3.08	2.29
	21	3.97	1.93	2.06
Conventional Till.	7	4.38	2.96	3.08
	14	4.00	2.62	2.73
	21	3.81	1.97	2.23
L.S.D (5%)	Tillage	0.52	NS	NS
	Irrigation	0.40	0.37	0.35
	Till Vs Irr.	NS	NS	NS

NS,Non significant

average values of 7 and 6 mm hr^{-1} were recorded for the chiselling and conventional tillage treatments. The higher infiltration rate under conventional tillage was believed to be a random phenomenon .

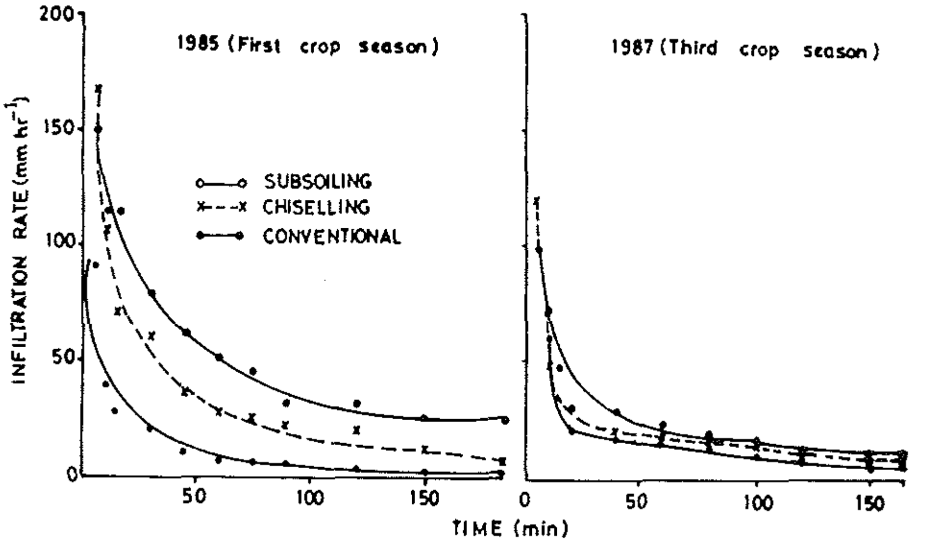

Fig.1 Effect of various tillage on the Soil infiltration rate

Bulk density

The tillage treatments significantly affected the bulk density at 5% probability level in the first year only (1985) and the carry-over (1986 and 1987) showed no significant effects. The bulk density at 0-10 and 30-45 cm depths did not change much over the three years for both treatments(Fig.2).

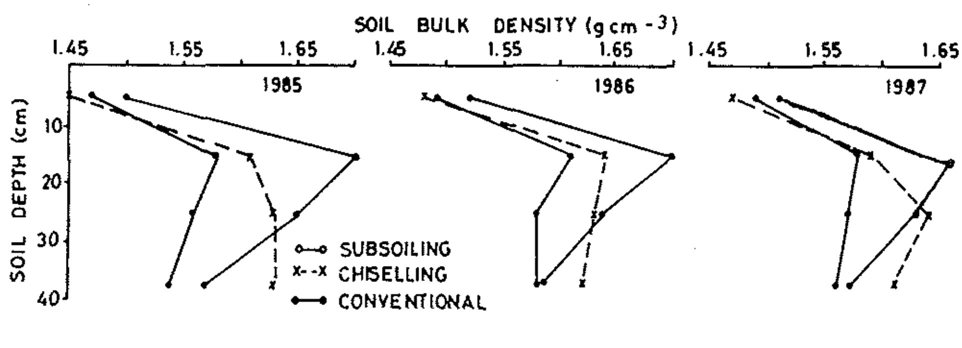

Fig.2 Effect of various tillage on the soil bulk density.

reports the findings of a study on the long term effects of deep tillage on soil physical properties and on grain yield irrigated wheat under the semi-arid region of Nigeria.

EXPERIMENTAL PROCEDURE

The experiment was conducted in the Kano River Project, Kadawa, Nigeria (11° 8′N, 8° 15′E), for three successive irrigation seasons during 1984/85, 1985/86 and 1986/87. The soil (Eutric Cambisol) of the experimental site is a deep loam texture and had been under intensive cultivation (twice a year) for almost 15 years. A split-plot design was used with tillage treatments as main plots and irrigation frequency as subplots. The tillage treatments were applied in the first year only the subsequent two years were carry-over, but conventional tillage was done on all the plots each year before planting. The tillage treatments use are (a) Subsoiling to a depth of about 35 to 40 cm, harrowed and rotavated; (b) Chiselling to a depth of about 25 to 30 cm, harrowed and rotavated and (c) Conventional tillage; consists of ploughing, harrowing and followed by rotavation before planting. The ploughing (through disc) penetrated to a depth of about 10 to 15cm.

An average irrigation water of 45 mm was applied under a basin system at 7-, 14- and 21-day intervals respectively designated by I_1, I_2 and I_3 irrigation treatments. The experiment was replicated four times giving 36 plots with each plot measuring 5 m x 5 m. Wheat variety Siette - Cerros was planted and the recommended 60 kg N; 60 kg P_2O_5 and 60 kg K_2O ha^{-1} was applied as basal dose fertilizer. A top-dressing of 60 kg N ha^{-1} was applied four weeks after planting. Irrigation frequency treatment was imposed after the second weekly irrigation and for all plots, irrigation was cut-off 13 weeks after planting. After harvest, two plots were randomly selected from each tillage treatment and infiltration rate was measured using double-ring infiltrometers. Four other plots were similarly selected on each treatment and undisturbed soil samples were taken from each plot for determining soil bulk density. The samples were taken at depths of 0-10, 10-20, 20-30 and 30-45 cm for each plot. A replicate of four samples were taken at each depth for a particular spot.

RESULTS

Infiltration Rate:

In the first year, the average terminal infiltration rate for the conventional tillage was found to be 3 mm hr^{-1}, and this was increased to 25 and 8 mm hr^{-1} by subsoiling and chiselling respectively. The carry-over in the second year showed a decreased infiltration rate (15 mm hr^{-1}) under the subsoiled plots, but chiselling and conventional tillage remained more or less the same being 8 and 3.5 mm hr^{-1} respectively (Fig. 1) At the end of the third year, the infiltration decreased to 10 mm hr^{-1} for the subsoiling and

THE EFFECTS OF DEEP TILLAGE ON IRRIGATED WHEAT PRODUCTION IN A SEMI-ARID ZONE OF NIGERIA

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ABSTRACT

Tillage pan could be so dense that it restricts root penetration and water intake resulting in lower grain yields. A tillage pan on an irrigated soil was broken by deep tillage; chiselling to a depth of 25 to 30 cm and sub-soiling to a depth of 35 to 40 cm so as to evaluate the long term effects of deep tillage and irrigation frequency (7-,14- and 21- day interval) on wheat production. The compacted tillage pan with a bulk density of 1.71 g cm^{-3} was located at 15 to 20 cm below the soil surface. Deep tillage treatments effectively break the tillage pan and increased infiltration rate by 3 to 8 fold but this declined in the later years. Subsoiling and chiselling reduced bulk density within the compacted layer to 1.58 and 1.61 g cm^{-3} respectively but just after one year, the bulk density in the subsoiled plots was increased to 1.61 g cm^{-3}. Irrigation frequency significantly affected grain yield irrespective of tillage treatment and the 7-day irrigation frequency consistently showed higher yields. The deep tillage significantly increased grain yield for the first year. In the carry-over, for the second and third years, the yield response was not statistically significant. A relative yield increase of more than 10% for two years was observed and chiselling was sufficient. Subsoiling exhibited higher yield increase, which progressively decreased over the three years. Poor correlation between yield and bulk density(10 - 30 cm soil layers) was observed at third cropping.

INTRODUCTION

In the large scale irrigation project, the land is mechanically cultivated twice in a year (rainfed and irrigated). Due to this intensive cultivation, tillage pans could very easily develop on these soils. The Kano River Project, Kadawa is one such area and tillage pans have developed. The soil infiltration rate for this area is very low, usually less than 5 mm hr^{-1}.

Deep tillage (chiselling or subsoiling) is usually used to disrupt and loosen the dense compacted pan. Deep tillage has been reported to effect higher yields, decrease bulk density and increase soil infiltration rate (Seve et. al., 1985; and Alegre et. al., 1986). Others have the contention that deep tillage is an advantage only when soil moisture is limiting (Robertson et. al., 1957; and Kamprath et. al, 1979). Porro and Cassel (1987) observed that the effects of deep tillage on grain yield are transitory. Under normal tillage operation, a tillage pan (previously subsoiled) may begin to reform within a year and reduced subsequent plant growth. For how long can deep tillage affect grain yield? This paper obtained with conventional tillage (MDT) can therefore mainly be attributed to larger plants, as tillage treatments did not affect the growth period and differences in plant populations did not correlate well with differences in LAD. Under dry land conditions, leaf-area normally correlates well with root development, because water and mineral supply to the plants depends on the size of the rooting system (Watson, 1968). In this study, rooting depth proved to be the most important factor ($r^2 = 0.72$) that attributed to a larger LAD. As also found by Russell and Goss (1974), results showed a good correlation ($r = 0.91$) between rooting depth and soil strength as measured with a penetrometer. This instrument therefore provides an excellent method to assess the suitability of a soil for no-tillage.

The absence of differences in yield, in spite of shallower rooting systems on no-tilled soil in the 1983-1985 years, showed that this disadvantage of no-till was of lesser importance when high nitrogen-fertilizer rates were applied. Similar results were obtained with dryland cereals in Australia (Jarvis, 1982).

CONCLUSIONS

1. Reduced and no-tillage resulted in lower wheat yields on shallow, stony soil in a mediterranean climate. This is mainly the effect of higher soil strengths which enables sufficient root penetration.

2. Penetrometer readings showed to be a reliable method to assess the suitability of a soil for no-tillage.

3. This disadvantage of no-tillage can, at least in some years, be minimized by higher nitrogen applications.

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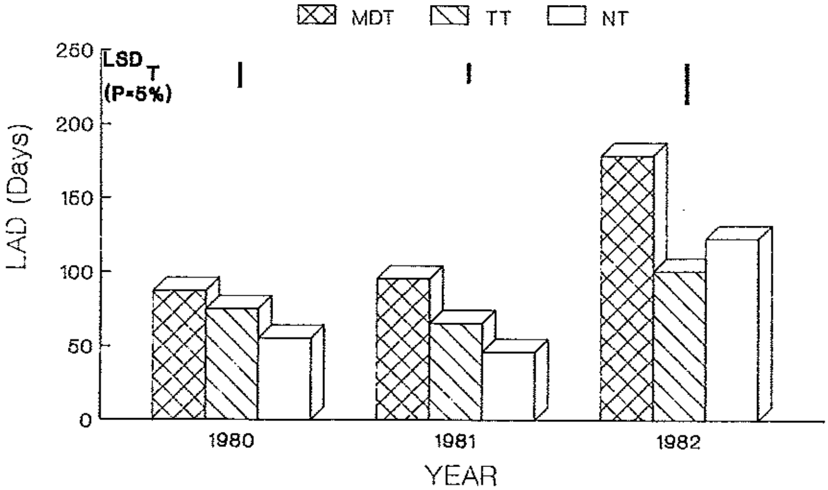

Fig. 3. Effect of tillage practices on total leaf-area duration (LAD) of wheat.

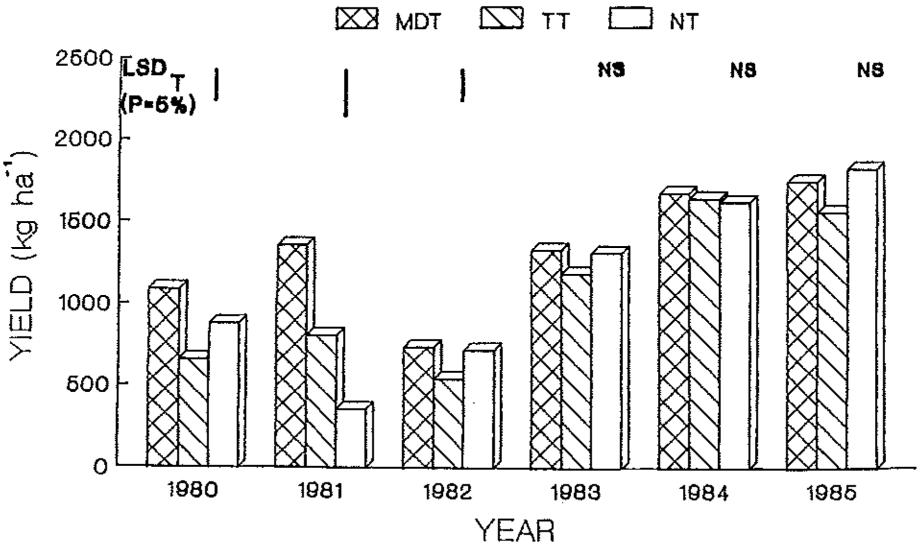

Fig. 4. Effect of tillage practices on grain yield of wheat.

This indicated that soil strength in both the TT and MDT soil stayed very low within the depth range of the primary tillage whereafter it started to increase. As shown by Soane, **et al.** (1975) and Soane, Dickson and Campbell (1982) on several European soils, this experiment on a shallow stony soil also indicated a significant increase in soil strength in the upper soil profile as a result of no-tillage. Below the normal tillage depth these differences decreased while differences between mouldboard (MDT) and tine-tilled (TT) soil corresponded with differences in the depth of tillage. This observation was also made by Soane and Pidgeon (1975).

Root development

In all treatments wheat roots elongated very rapidly during the first 40 days after seeding, but after that the rate decreased. In the no-till treatment the decline in root elongation was more rapid than in other treatments, resulting in a significant shallower rooting system than in the conventional (MDT) and tine-tilled (TT) treatments. As shown in Fig. 2 wheat roots penetrated only 146 - 176 mm into untilled (NT) soil. In the conventional tilled (MDT) soil roots penetrated between 180 and 200 mm in different years. In the tine-tilled (TT) soil roots penetrated deeper than in untilled (NT) but slightly shallower than in ploughed (MDT) soil. Although wheat roots penetrated significantly deeper in conventional tilled (MDT) than in the untilled (NT) soil, roots ceased to elongate in the former soil at a soil strength of only 2.37 MPa. In the no-till treatment maximum rooting depth indicated that roots can overcome soil strenghts up to 3.75 MPa. This tendency is probably due to a difference in soil structure as discussed by Soane and Pidgeon (1975).

Leaf-area duration (LAD)

Total leaf-area duration of the wheat crop increased with increasing tillage depth. Fig. 3 clearly shows that LAD was the lowest where no-tillage (NT) was practised and the highest on plots that were ploughed to a depth of 200 mm (MDT). Where the soil was tine-tilled to a depth of 150 mm, LAD was higher than in no-tilled, but lower than the conventional tilled (MDT) plots. As the different tillage methods did not affect the growth period of the wheat and differences in plant population did not correlate well ($r = 0.32$) with differences in LAD, the shown differences in LAD must be due to larger leaf-areas of single plants where conventional tillage (MDT) was applied.

Grain yield

Grain yield of all treatments increased in the 1980 to 1985 period (Fig. 4). In 1980 and 1981 conventional tillage (MDT) produced significantly higher yields than both tine- (TT) and no-tillage (NT). In

1982 yields of the conventional (MDT) plots were only significant higher than that of the tine-tilled (TT) plots, while yields obtained with tine-(TT) and no-tillage (NT) compared very well with that of conventional tilled (MDT) wheat in the 1983 to 1985 period.

DISCUSSION

During the 1980-1982 period conventional tillage (MDT) outyielded less intensive tillage treatments (TT and NT). These differences in yield correlated very well ($r = 0.79$) with total LAD. The higher yields

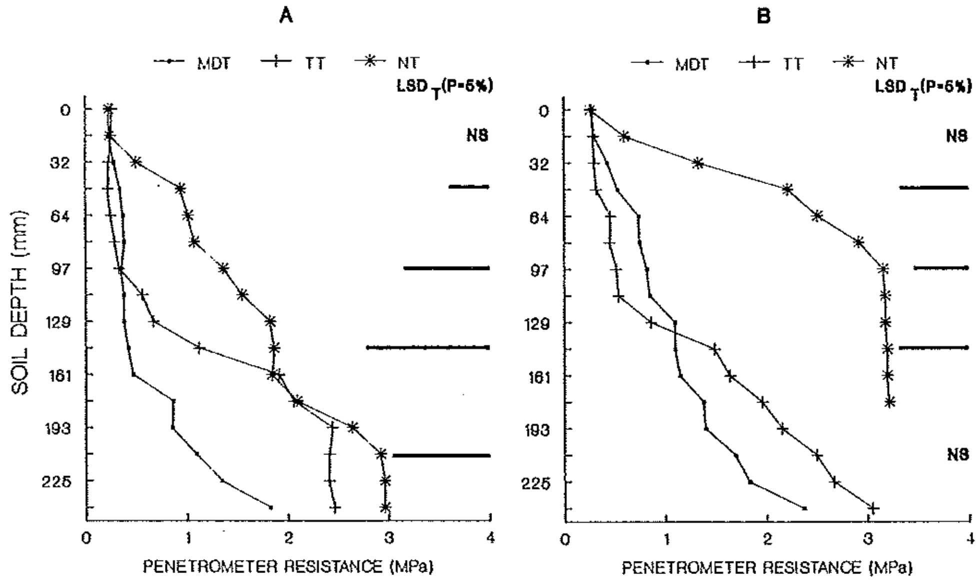

Fig. 1. Change in penetrometer resistance of a stony soil as a result of different tillage practices in 1981 (A) and 1982 (B).

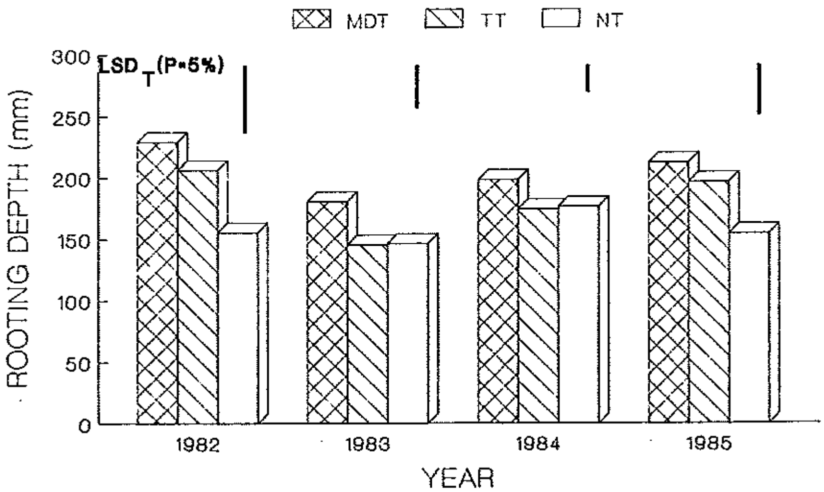

Fig. 2. Effect of tillage practices on maximum rooting depth of wheat.

(i) The conventional system (MDT) where the primary tillage was conducted with a mouldboard plough (200 mm deep) after the first autumn rains in April. Before seeding in May these plots were disced to a depth of 120 mm.

(ii) In the tine-tillage (TT) system the primary tillage was done with a chisel plough (150 mm), followed by a shallow (100 mm) field cultivator treatment before seeding.

(iii) In the no-tillage (NT) system, remaining stubble of the previous crop was burnt in March, while volunteer wheat plants and weeds were sprayed with a non-selective herbicide before seeding with a triple-disc seeddrill.

Post-emergence weeds were controlled chemically in all treatments while nitrogen was applied at a rate of 55 kg N ha^{-1} in 1980 and 1981 whereafter it was increased to 65 kg N ha^{-1} in 1982 and 1983. In 1984 and 1985 nitrogen was applied at rates of 80 and 100 kg N ha^{-1}.

Table I Properties of the experimental soil

Soil texture	Sandloam
Soil depth	250 - 300 mm
Clay content	8 %
Stone (> 2 mm) content	44.6 %
Water content at - 10 kPa	11.25 % m/v
Soil pH (KCl)	5.0

Although a wide range of soil and crop properties were investigated this paper will only deal with soil strength, root development, leaf-area duration (LAD) and grain yield.

In 1981 and 1982 soil strength was measured with a manual penetrometer within the first 30 days after seeding. This penetrometer was fitted with a 10 mm ϕ pen and a 30^{o} cone tip (25 mm in length).

Root development was measured fortnightly in all years from 1982 to 1985, by digging a hole across the direction of the wheat rows determining the depth roots had penetrated in the soil profile.

LAD was also determined fortnightly in the years 1980 to 1982. Total area of green leaves of plants on an 0.25 m^2 area was measured.

At the end of the season (October) a plot harvester, which reaped a strip of 1.25 m along the length (50 m) of each plot, was used.

RESULTS

Soil strength

Soil strength, as measured with a penetrometer, increased sharply in the 0 - 50 mm soil profile of the no-till (NT) plots in both years (Fig. 1). In the tine-tilled (TT) treatments the soil did not offer much resistance to the penetrometer till depths of 97 to 113 mm were reached. With deeper penetration the resistance increased sharply. The conventional tilled (MDT) soil showed the same trend but penetrometer resistance only increased after depths of approximately 161 - 193 mm.

THE EFFECT OF TILLAGE ON ROOT ENVIRONMENT, PLANT DEVELOPMENT AND YIELD OF WHEAT (Triticum aestivum) IN STONY SOIL

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ABSTRACT

A field experiment conducted over ten years in the mediterranean wheat-producing area of South Africa, examined the effect of conventioned mouldboard- and disc-tillage (MDT), tine-tillage (TT) and no-tillage (NT) on the structure of the root environment of a shallow, very stony sand-loam soil. Crop responses to these tillage-induced differences in the root environment were also investigated. No-tillage soil showed the highest penetrometer resistance while differences between conventional (MDT) and tine-tilled (TT) plots related to differences in the depth of the primary tillage. Penetrometer resistance of the soil correlated linearly with the depth that wheat (Triticum aestivum) roots penetrated, but resistance at which root elongation ceased, differed according to the intensity of tillage. Reduced rooting ability of plants on compacted NT soil were reflected in lower leaf-area durations (LAD), and grain yields.

INTRODUCTION

In contrast to deep, fertile soil (Hargrowe and Hardcastle, 1984; Osborne, 1984 and Cannell, 1985), scant research is done on the effect of reduced and no-tillage on shallow, stony soil. A high stone content (over 25 %) created tilth and mechanical difficulties during drilling, which reduced the depth of drilling and seed cover (Wilkonson, 1975), while soil compaction, due to reduced and no-tillage is a feature common on most soils (Soane, Butson and Pidgeon, 1975).

Because most soils of the mediterranean wheat-producing area of the Republic of South Africa are very shallow and stony a study was conducted to examine the feasibility of reduced and no-tillage as a tillage practice for cereal production in these areas.

METHODS AND MATERIALS

The experiment on a shallow stony soil (Table 1) at Langgewens experimental farm in the Western Cape wheat-producing area of the Republic of South Africa, started in 1976. This article, however, will only deal with results obtained during the 1980 and 1985 period because earlier results (1976 - 1977) were affected by the tillage methods used in the land prior to the beginning of the experiment while very dry conditions in 1978 and 1979 resulted in very low yields in all experimental treatments. In the years 1980 - 1985 rainfall figures showed a typical mediterranean pattern with almost 80 % of the total fall (350 - 450 mm) in the months April to September.

In the experiment, which compared the following tillage treatments, spring wheat was grown in all years:

SECTION 5

CONSTRAINTS AND ADVANTAGES OF MODERN TILLAGE SYSTEMS

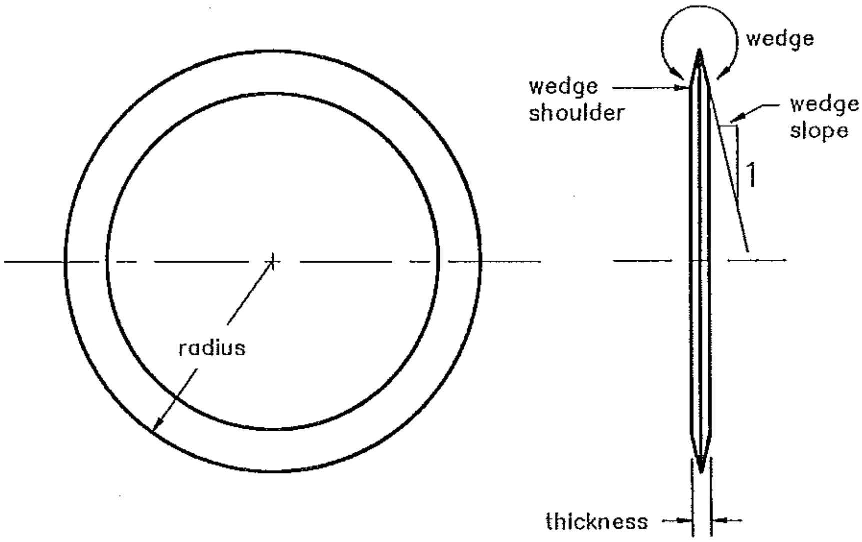

Figure 1. Coulter geometry.

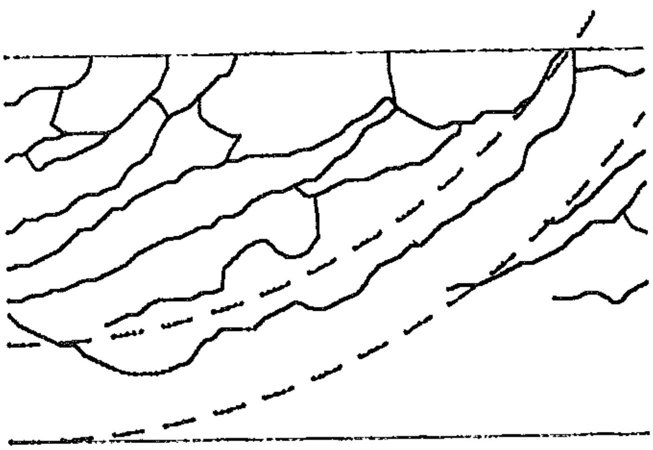

Figure 2. Typical crack patterns in a coulter furrow wall.

Since all forward and vertical displacements, both at the surface and below the surface, appeared to have negligible influence on the coulter force, we will assume for the coulter force model that the displacement everywhere on the soil-coulter interface has only a lateral component, and no forward or vertical components.

CONCLUSIONS

1. The forward displacement of soil at the surface was negligible. Some upward displacement occurred, but appeared to be due to sliding of distinct blocks of soil and/or to soil being lifted by the back of the coulter.

2. Below the surface, both vertical and forward displacements were negligible.

3. Displacements over the entire soil-coulter interface can be estimated by lateral components alone. This estimation will be used to approximate soil motion and calculate the direction of the sliding resistance on the coulter surface, thus relating the soil pressures to the coulter forces.

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concluded that this part of the displacement had negligible influence on the coulter force. Since the portion of the vertical displacement occurring before separation was very small, it was concluded that the influence of this portion was also negligible.

Forward displacements at the surface were typically less than 1 mm and could not be detected by measuring the location of the chalk mark at the furrow edge. Where larger displacements occurred, they appeared to be a result of the soil being lifted by the back of the coulter. Thus, it was concluded that forward displacements had negligible influence on the coulter force.

The lifting of the soil by the back of the coulter was contrary to the simplifying assumptions for approximating the soil motion for the coulter force model. For a particle to remain in contact with the coulter, lateral movement can occur only at the wedge, and not at the flat face. For movement in a straight line, the ratios among the three orthogonal components must be constant. Thus, no soil motion in any direction can occur at the flat faces by these assumptions, contrary to the observed lifting action. However, only a layer of soil near the surface was being lifted, and the pressures measured near the soil surface on the flat faces of the coulter were small. Thus, the sliding resistance must also have been small, and it was concluded that the soil lifting by the flat face had negligible influence on the coulter force.

Soil deformation by the coulter produced crack patterns in the furrow walls, as illustrated in Figure 2. This figure represents a perpendicular view of the vertical furrow wall. The horizontal lines represent the soil surface and the bottom of the furrow. The dashed curves represent the profiles of the coulter edge and the wedge shoulder. The direction of coulter travel was from left to right. The crack pattern was determined from a photograph of a furrow wall for the clay loam soil and a coulter having 8 mm thickness, 0.12 wedge slope, and 120 mm coulter depth. Distinct blocks in the surface layer can be seen in this crack pattern. The cracks forming the bottoms of the blocks are failure surfaces which sloped upward away from the furrow to the soil surface. Below the blocks, the cracks extended a limited distance away from the furrow.

Vertical displacements on the soil surface had appeared to result primarily from the sliding of the distinct blocks and from soil being lifted by the back of the coulter. Since neither action occurred below the surface layer, it was concluded that vertical displacements below the surface were very small. Forward displacements at the surface were too small to measure, except where they resulted from lifting at the back of the coulter, and the deformation patterns provided no evidence that forward displacements below the surface were greater than those at the surface. Thus, it was concluded that both forward and vertical displacements below the surface had negligible influence on the coulter force.

Table II. Coulter dimensions.

Thickness nominal, mm	Thickness actual, mm	Wedge slope	Coulter radius, mm
8	7.2	0.12	252
8	7.6	0.25	253
12	10.5	0.12	252
12	11.3	0.25	254

wedge slopes (Figure 1). Dimensions of the four coulters are listed in Table II. Coulter depths of 50 to 100 mm, wedge slope of 0.12 and thicknesses of 4 to 6 mm are typical of commercial coulter applications, but thicknesses of 6 mm or less could not be fitted with commercially available miniature transducers for measuring pressure.

Soil displacements were specified in terms of three orthogonal components: forward, vertical and lateral (perpendicular to the direction of coulter travel). Forward and vertical displacements at the soil surface were determined from the deformation of straight lines perpendicular to the direction of coulter travel. These lines were marked with chalk and the displacements were measured at the furrow edge. The lateral displacement at the furrow edge was assumed to be one-half the thickness of the coulter, that is, the furrow wall was assumed to be composed of particles moved from the center of the furrow. The subsurface displacement at a point (for example) 40 mm above the bottom of the coulter furrow was assumed to be similar to the displacement at the surface for a coulter depth of 40 mm. Some differences between surface and subsurface displacements were indicated by differing deformation patterns, and these differences were incorporated in the estimates of subsurface displacements.

RESULTS AND DISCUSSION

Vertical displacements at the surface were typically between 1 and 15 mm upward. However, lifting of the soil behind the coulter center was frequently observed during coulter operation. This lifting occurred at the flat face as it rotated upward out of the soil and appeared to account for the larger vertical displacements. Some vertical displacement may have occurred at the leading edge, but this displacement appeared to be associated with the formation of shear failure surfaces approximately 10 to 20 mm below the soil surface. These failure surfaces sloped upward away from the furrow, and distinct blocks of surface soil were separated from the soil below. Sliding of the blocks, after separation had occurred, apparently accounted for the majority of the upward displacement at the leading edge. Because separation of the blocks from the subsurface soil would reduce the resistance to the coulter motion, it was estimated from displacements at the surface and from soil deformation patterns.

Two simplifying assumptions will be used to approximate soil motion in the coulter force model: 1) the soil particles move in a straight line and 2) they always remain in contact with the coulter. The direction of the soil motion can then be determined from the measured or estimated displacement, and the position and speed along the straight line will be determined by the coulter location and forward speed.

OBJECTIVES

The specific objectives of this study were:

1. To determine the surface soil displacements along the path of freely rolling coulters;

2. To determine the type of subsurface deformation which occurs over the soil-coulter interface; and

3. To estimate the soil displacements over the interface.

METHODS

All tests were performed in the soil bins of the National Soil Dynamics Laboratory[1]. The coulters were moved through the soil at a forward speed of 0.5 m/s. A lateral spacing of 0.6 m minimized interactions between furrows. Coulter forces and pressures on the coulter surface were measured during each test. Tice et al. (1987) reported the results of the pressure measurements and details of the experimental equipment and methods.

Tests were conducted in the two soils described in Table I for coulter depths of 40 mm, 80 mm and 120 mm and for coulter geometries comprising two nominal coulter thicknesses and two

Table I. Soil conditions.

Soil	Sand/silt/clay	Bulk density*, Mg/m^3	Moisture content*, db**	Cone index*, MPa
Norfolk sandy loam	0.72/0.17/0.11	1.62	0.07	1.1
Decatur clay loam	0.27/0.43/0.30	1.40	0.12	1.5

* Average over 120-mm depth
** db - dry basis

[1] For a description of the NSDL research facilities, a brochure may be obtained from the National Soil Dynamics Laboratory, POB 792, Auburn, AL 36831 U. S. A.

SOIL DISPLACEMENT BY ROLLING COULTERS

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ABSTRACT

To provide a better understanding of soil-coulter behavior, a coulter force model is being developed which incorporates soil-coulter sliding resistance. The direction of the sliding resistance depends on soil displacement. Therefore, soil displacement by rolling coulters was determined for four coulter geometries, three depths of operation and two soils. On the soil surface, forward displacements were negligible, and upward displacements occurred mostly after the surface layer had separated into distinct blocks. Below the surface, distinct blocks were not formed. It was concluded that the forward and vertical components of soil motion had negligible influence on the coulter force and that only lateral displacements were important in the development of a coulter force model.

INTRODUCTION

Freely-rolling coulters are essential components of tillage and planting implements for conservation farming systems. To ensure optimal design and use of coulters on these implements, a coulter force model is being devised. As one part of developing this model, Tice et al. (1987) measured soil pressures on coulters. These pressures provide a basis for estimating the magnitude of the sliding resistance at any point on the coulter. However, the direction of sliding must be known before the sliding resistance can be related to the draft and vertical components of the coulter force.

The direction of soil sliding on the coulter is determined by both the motion of the coulter and the motion of the soil. The motion of the coulter is easily measured (Tice and Hendrick, 1986), but direct measurement of soil motion is extremely difficult, if not impossible. The soil motion may be approximated if the soil displacement by the coulter from original to final position can be determined. But measuring the displacements below the soil surface would also be difficult. Therefore, subsurface displacements were

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DISCUSSION AND CONCLUSIONS

Cultivation treatments for cereal sowing which incorporated chopped straw, when assessed by crop yield results cannot be conclusive with results from only one year. However, there are indications that in heavy land higher plant establishment is obtained by the use of the SCAE prototype implement, by rotary digging or by using a disc/tine implement when compared with the other treatments.

Observation of the soil profiles from the different cultivation treatments suggest that there is a more intimate mix of straw and soil with the SCAE prototype implement and rotadigger, but both these machines left some straw on the surface. Mouldboard ploughs with either skims or trash boards fitted left a virtually straw free surface, but did not provide quite the degree of soil/straw mixing as the former two machines. Neither the disc/tine cultivator or the rotary cultivator achieved much success at mixing or burying straw.

Although none of the machines incurred statistically significant yield penalties or gains, implements like the SCAE prototype fulfilled the requirements of complete dispersal of straw throughout the cultivated profile well. In addition, a considerable degree of soil comminution was achieved and this was reflected in lower tractor fuel consumption for complete cultivations systems. With this type of machine there is also the advantage that materials other than straw, such as sewage sludge, may be successfully incorporated, thus increasing the versatility and cost effectiveness of the implement to the user.

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Plant establishment

Plant establishment data for winter barley at site 1 and winter barley at site 2 are shown in Figure 3. The highest plant establishment was obtained on plots cultivated using the SCAE prototype machine at site 1 (sandy loam) although the differences between the treatments were not statistically significantly different. However, at site 2 (clay loam) plots cultivated using the Rotadigger had significantly more ($P \leq 0.05$) plants compared with plots prepared using the mouldboard plough with either skims or trash boards; in addition plots of both the SCAE prototype and the disc/tine cultivator had significantly greater ($P \leq 0.05$) plant establishment figures than those of the mouldboard plough with trash boards.

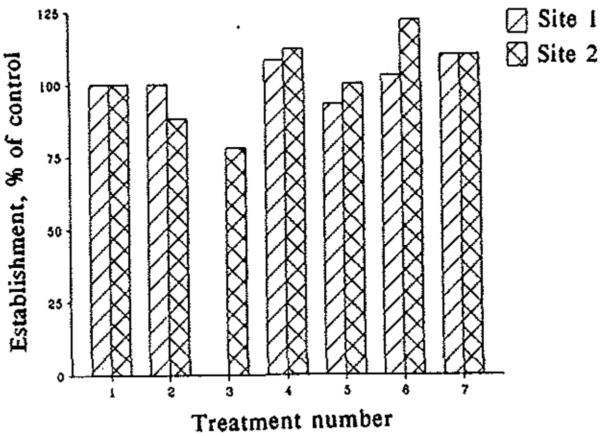

Fig. 3. Effects of treatments on crop establishment

Crop yields

Grain yields for sites 1 and 2 are shown in Figure 4. Yields from all the treatments at both sites were not statistically significantly different (at $P \leq 0.05$ level), and no correlation between yield and plant establishment existed. On the sandy loam of site 1 the highest yields were from two of the mouldboard ploughing treatments, one of which was the control where straw had been removed. These yields were close to those on the plots of the disc/tine implement and the SCAE prototype. On the clay loam soil of site 2 the highest yield was recorded on plots cultivated by the disc/tine implement, closely followed by the SCAE prototype cultivator.

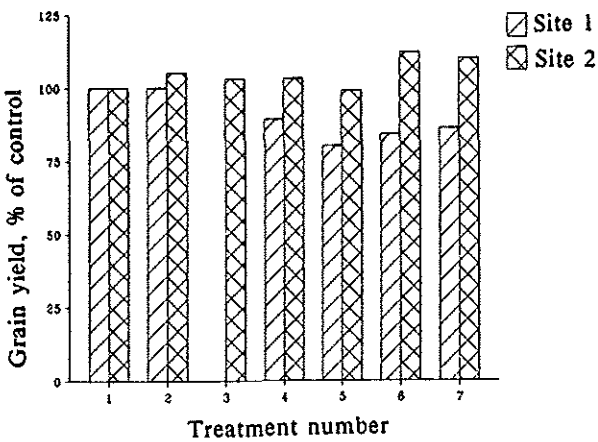

Fig. 4. Effects of treatments on crop yield

Observations on cultivation and straw incorporation

Cultivation and straw incorporation effects were similar on both soil types. Observations on cultivation and digitised profiles were as follows.

Treatment 1. There was little straw to bury and a broken furrow with a clean soil surface was left.

Treatment 2. The straw was buried to the depth of ploughing and between the furrow slices. A broken furrow with a clean soil surface was left.

Treatment 3. The straw was buried to the depth of ploughing and partially incorporated between the furrow slices. A broken furrow was left with a few wisps of straw on the surface.

Treatment 4. Some straw was buried and some mixed in the top layers of soil but approx. 25% was still visible. The land was left in a series of small ridges comprising a mixture of straw and soil. Some seedbed tilth was prepared.

Treatment 5. About 50% of the straw was still visible after cultivation. The straw that had been incorporated was mixed only in the topmost layer of soil. A shallow tilth was prepared.

Treatment 6. The straw was well mixed down to cultivation depth. A coarse tilth was produced with a little straw visible on the surface.

Treatment 7. Straw was well mixed with the soil throughout the depth of the profile. A medium tilth was produced with only a little straw still visible on the surface.

The distribution of straw within the cultivated layer following incorporation by the mouldboard plough with skims (treatment 2), the disc/tine cultivator (treatment 4), the spike tine rotary cultivator (treatment 5), and the SCAE prototype (treatment 7) is shown in Figure 2.

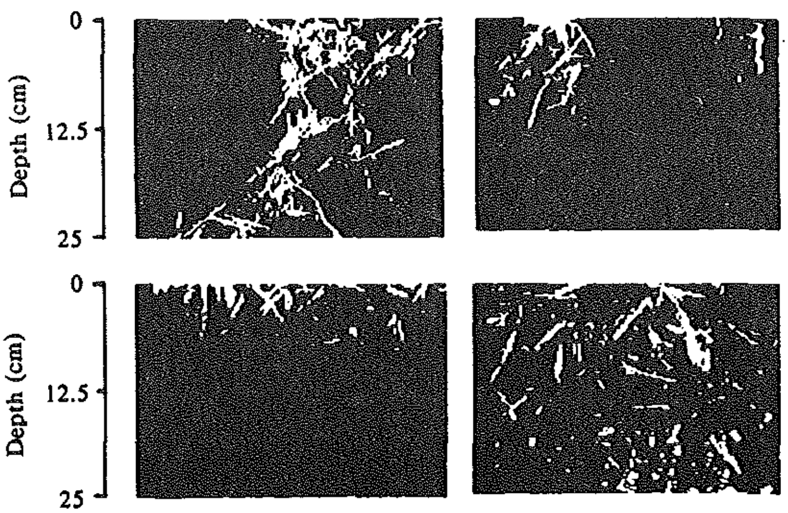

Fig. 2. Digitised data of straw after incorporation by mouldboard plough with skims (top left), disc/tine cultivator (top right), spike tine rotary cultivator (bottom left) and SCAE prototype implement (bottom right).

However, results were very variable, even between replicates of the same treatments, so no figures have been quoted here. Nevertheless, visual comparison of the digitised profiles provided excellent information on the effectiveness of the treatments.

RESULTS

Power requirements and work rates

Power consumption measurements were made of the draft and pto requirements of the SCAE prototype implement working in a loam and in a sandy clay loam. Draft measurements were also made of a conventional 6-furrow mouldboard plough, having the same working width as the SCAE implement, in a loam soil. The results are shown in Table II.

TABLE II Power consumption of SCAE prototype implement compared with mouldboard ploughing

Implement	Soil type	Working width, m	Work rate, ha/h	Power consumption, kW		
				draft	pto	total
Mouldboard plough	Loam	2.40	0.83	28	nil	28
SCAE prototype	Loam	2.40	0.80	26	18	44
SCAE prototype	Sandy clay Loam	2.40	0.75	28	20	48

There was a slight reduction in draft of the SCAE prototype over a mouldboard plough at approximately the same work rate in loam soil, but the overall power was appreciably increased through the pto requirement. However, the degree of soil comminution achieved by the SCAE machine was much greater than a conventional plough, and this was shown by the overall reduction in tractor fuel consumption of a complete cultivation system using the SCAE prototype for primary cultivation rather than a plough, or even disc/tining a burnt stubble (Table III).

TABLE III Tractor fuel consumption in tillage experiments for winter wheat on clay, 1986-87 (Patterson, 1987)

Cultivation system (No. of passes in brackets)	Straw disposal method	Fuel consumption, l/ha	
		Individual operations	Total for system
Plough		24.4	
Secondary cultivator (3)	chopped	16.0	
Drill, roll		6.9	47.3
Shallow plough	chopped	14.9	
Secondary cultivator (3)		15.7	
Drill, roll		6.5	37.1
Disc/tine (2)	removed	20.6	
Secondary cultivator (2)	burnt stubble	9.2	
Drill, roll		6.4	36.2
SCAE prototype	chopped	18.2	
Secondary cultivator (2)		10.6	
Drill, roll		6.6	35.4

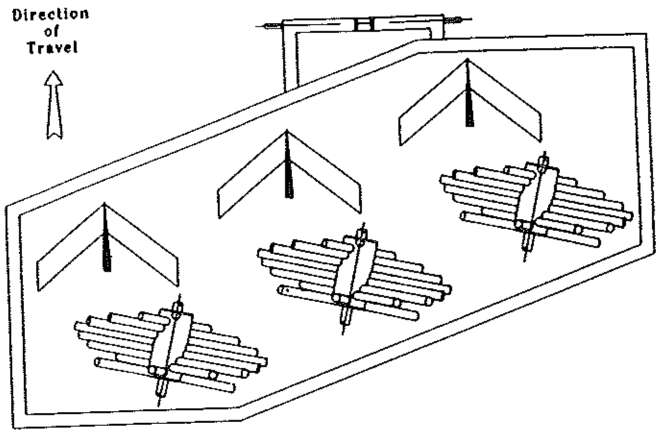

Fig. 1. Diagramatic layout of tines and rotors on SCAE prototype

METHODS OF EVALUATING THE EFFECTIVENESS OF STRAW INCORPORATION

Field experiments

The performance of the new implement was compared with six other cultivation implements (Table I) at two sites near SCAE. At site 1 winter barley was grown on a sandy loam (Darvel series), and at site 2 winter wheat was grown on a clay loam (Winton series).

TABLE I Details of treatments

Treatment No.	Straw disposal method	Implement
1	Removed	Mouldboard plough with skims (control)
2	Chopped and spread	Mouldboard plough with skims
3	Chopped and spread	Mouldboard plough with trash boards
4	Chopped and spread	Disc/tine cultivator
5	Chopped and spread	Spike tine rotary cultivator
6	Chopped and spread	Rotadigger
7	Chopped and spread	SCAE prototype implement

Evaluation of soil straw mixing

Techniques used in the past have ranged from simple visual assessments of the percentage straw cover on the surface and in the soil profile (Chittey *et al.*, 1986; Turley *et al.*, 1986) to the time consuming removal of successive layers of soil, from which the straw is then removed by sieving, and subsequently washed. Whilst these methods are useful, neither gives a particularly accurate indication of the distribution of straw in a vertical cross-section of soil.

Because there is generally a high visual contrast between recently incorporated straw and cultivated soil, a method was developed using a low cost video image analysis system with a micro-computer, to measure the spatial distribution of straw in soil (Rackham and Sharp, 1986).

Vertical profiles were taken to a depth of approx. 25 cm followed by photographs of the soil profile, digitisation and storage of photographic images and analysis of data.

A NEW ROTARY TILLAGE IMPLEMENT FOR INCORPORATING STRAW AND OTHER MATERIALS INTO SOIL

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ABSTRACT

A new rotary tillage implement is described which consists of "A" blade shares followed by tined rotors. The design gives the implement the ability to produce good soil/trash mixing and soil comminution at satisfactory power consumption levels and overall work rates. The performance of the machine is compared with a number of other implements at different sites when incorporating chopped straw. Parameters measured include: degree of soil/straw mix, crop establishment, final yield and power consumption.

INTRODUCTION

Following public concern on straw burning in the UK during 1983 and 1984, work was undertaken at the Scottish Centre of Agricultural Engineering on the design and development of a tillage implement to incorporate straw and other materials, as well as to act as a general purpose tillage machine having a low power requirement and the ability to produce a good tilth.

The problems of incorporating straw tend to be more severe under Scottish conditions (Pascal *et al.*, 1985) and consequently greater demands are placed on machinery for this purpose. Because the harvest is later, soil temperatures at the time of incorporation are lower than in Southern England and much of Europe. The rate of straw humification is directly related to soil temperature, and as soil temperatures are also lower at greater depths, it is not always advisable to bury straw deeply to keep it away from emerging seedlings. Similarly, if large amounts of straw remain close to the surface, the grower faces the possibility of emerging seedlings being inhibited by toxins and certain pathogenic fungi. The solution is to mix straw evenly throughout the depth of the cultivated profile, and retain a largely straw-free surface.

DESCRIPTION OF THE SCAE PROTOTYPE CULTIVATOR

The SCAE design is pto driven and consists of three tined helical rotors, angled at 13^{o} to the direction of travel (Fig. 1). Each rotor is slightly staggered behind the adjacent one working in front of it, and each has a working width of 53 cm. Thus the rearward overhang of this mounted implement when lifted, is much reduced compared with a mouldboard plough of the same working width. Preceding each rotor is an 'A' blade tine to lift and loosen the soil. The following tined rotors, turning at approx. 80 rev/min, cultivate the soil whilst simultaneously mixing chopped straw or other material evenly throughout the depth of the cultivated profile, typically 20-25 cm. Subsequent to its initial trials the implement is now being manufactured by Falcon Farm Machinery Ltd., of Stafford, under the trade name of the "Sturplow".

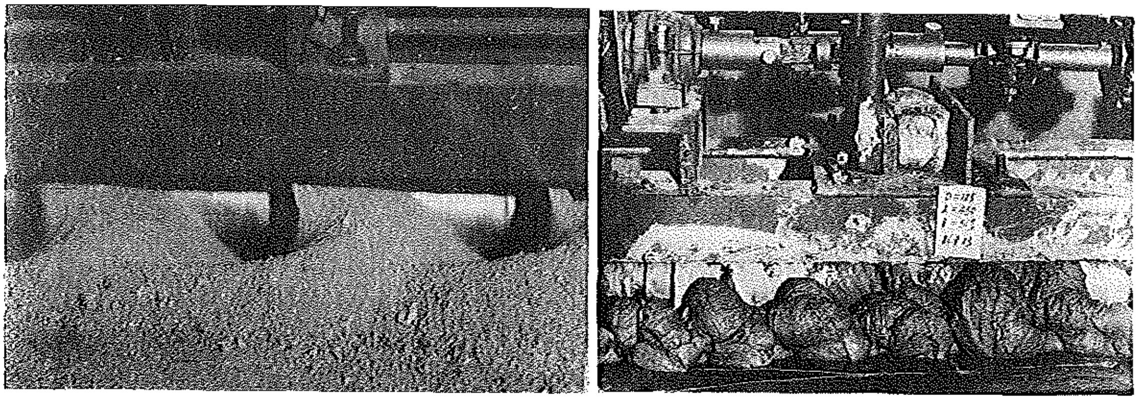

Fig. 5 Soil flow beneath screw in sand (left) and in clay slurry(right)

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observed. It was found that the soil particles had some displacement from top layer to bottom layer and that some disturbance on positions of all the white dots was clearly shown in Fig. 4. The adhesion and soil-metal friction gave a significant effect on the flow of soil particles beneath boat.

In paddy soil with water film 2mm in thickness, it was shown from photographs that all the white dots beneath moving boat bottom remained on their own positions as if there were no soil flow being happened. The sliding resistance of boat in this condition was only one half to one third of that with-out water film because the soil deformation was very very small.

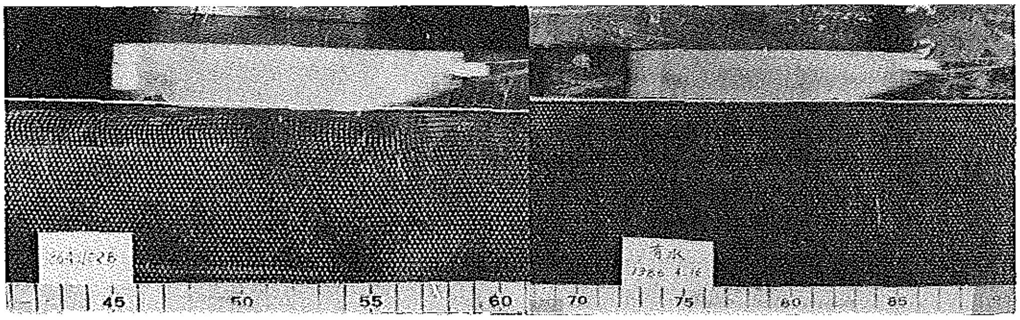

Fig. 4 Soil flow beneath sliding boat on paddy soil without water film (left) and with water film in 2mm thickness (right)

SEMI-EMPIRICAL FORMULA FOR PREDICTING SLIDING RESISTANCE OF SLIDING BOAT

A semi-empirical formula was developed to express the sliding resistance of floating boat:

$$R_s = k_1 v + k_2 A(c_a + p_0 \tan\delta)$$

where R_s is the sliding resistance in N, k_1 and k_2 are the resistance coefficients, according to statistical regression $k1 = -68 + 4380p_0$, $k_2 = 0.015 - 0.028$, v is the speed of boat in m/s, A is contact area of boat with soil in cm^2, c_a is soil adhesion in kpa, p_0 is contact pressure of boat on soil in kpa, and δ is soil-metal friction angle in degree.

The measured and predicted values of the sliding resistance in paddy soil are found in good correlation.[11]

SOIL FLOW BENEATH SCREW IN SAND AND CLAY SLURRY ; FORMULA FOR PULL

The soil flow beneath rotating screw was a three dimension flow movement(in longitudinal flow and lateral flow). In experiments the soil flow beneath screw at left side view and at right side view were very different. In order to observe the soil flow beneath screw of both sides it was better to take photographs from double sides of soil box.

The soil flow beneath screw in sand at 0.8slip and in clay slurry at 0.5slip are shown in Fig.5.

A semi-empirical formula had been derived for screw on slurry paddy to calculate the pull based on rheological theory and regression of measured data.

$$F_s = \frac{2(A_0 - A_1)\tau}{d+h} \cot\left[\tan^{-1}\left(\frac{d + D}{4di\tan\alpha}\right)\right] \quad \text{(in N)}$$

$$\tau = 2.574\,v\,(1 - e^{-0.71t}) + 0.59\,vt$$

where v,t- forward speed(m/s) and time(s), τ- shear(kpa), $A_0 A_1$- initial and finalcontact area (cm^2), D,d,α-tip,bottom diam. and angle of screw, i-slip.

EFFECT OF TILLAGE ROTATIONS AND CROPPING SYSTEM COMBINATIONS ON SOIL PROPERTIES AND YIELD OF CORN AND COWPEA.

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ABSTRACT

Comparative effects of no-tillage and conventional tillage rotations on soil properties and crop yields were determined across four cropping sequences over 10 successive cropping seasons. Soil parameters monitored included structural stability, total porosity, soil water storage, infiltration and organic matter. Soil and crop response was significantly affected by tillage rotations and cropping systems in specific combinations. Deterioration of soil properties increased relative to length of conventional tillage in rotation and decreased along cropping sequence of continuous cowpea, continuous corn, cowpea-corn, and corn-cowpea. Interactions between tillage rotations and cropping systems were significant for corn development rates and yields. The relative potential of various combinations of tillage and cropping rotations in sustaining soil properties and crop yields is discussed.

INTRODUCTION

Considerable comparative tillage studies have established the superiority of no-tillage over conventional tillage methods in continuous farming. Experience in Nigeria indicates that use of conventional tillage results in rapid deterioration of soil conditions (Wilkinson, 1975; Lal, 1976; Aina, 1979a; Lal, 1985). No-tillage with crop residue mulch has a number of benefits (Baeumer and Bakermans, 1973; Lal, 1985) which suggest its potential as an attractive alternative to the conventional method in minimizing soil deterioration. How ever, some intractable problems may prevent the continuous use of no-tillage in farming.

Apart from specific soil and machinery requirements, and non-adaptability to systems involving crops with tuberous underground parts such as cassava (Manihot esculenta) and yams (Dioscorea spp) that require conventional seedbed for their normal development and ease of harvesting (Aina, 1979b; Okigbo, 1979), the effectiveness of no-tillage depends on effective chemical weed control and the provision of adequate amounts of durable residue mulch. In Nigeria, as most developing nations today, herbicides are increasingly unavailable or prohibitively expensive. Even in the developed nations, where chemicals are more easily and economically available, there is a growing objection to their prolonged use in agriculture because of their residual damage to the total environment (Arnon, 1984). These problems may inhibit the continuous use of no-tillage in farming.

Appropriate tillage rotations that alternate no-tillage and conventional systems therefore merit consideration in finding solutions to the problems of continuous no-tillage or conventional tillage methods in crop production. This report describes the effects of a long-term on-going experiment initiated in 1982 at Ife (Nigeria) University to investigate the effects of rotations of no-tillage and conventional tillage on soil properties and crop responses under different cropping systems.

MATERIALS AND METHODS

The experiment was established in 1982 at the Ife (Nigeria) University Teaching and Research Farm on an Iwo sandy loam (Oxic Paleustalf). Mean annual rainfall is 1350 mm, distributed bi-modally to give two growing seasons (March to July and August to November). The approximately 2-ha experimental site was in 25-year secondary forest prior to manual clearing for the experiment.

Tillage treatments imposed over the 10 growing seasons on 40 x 30m plots consisted of continous no-tillage (NT) with crop residue mulch and weed controlled by application of paraquat (1-1-dimethyl-4-4 bypyridinium ion) at the rate of 0.5kg a.i. ha^{-1}; continuous conventional tillage (CT) involving moldboard plowing followed by disc harrowing to a depth of 15cm; alternating CT with NT every season (C1N1); two seasons (one year) of CT followed by 2 seasons of NT (C2N2); two seasons of CT followed by 4 seasons of NT (C2N4) and 4 seasons of CT followed 4 seasons of NT (C4N4). The cropping treatments, allocated according to a split-plot randomized design with tillage treatments as main plots in three replications were continuous corn (Zea mays L), continuous cowpeas (Vigna unguiculata L. Walp), and annual rotations of corn-cowpeas and cowpeas-corn. Corn variety "TZSR-W" and Cowpea "Ife Brown" were used. Determinations described in earlier reports (Aina 1979a) were made periodically of bulk density, porosity, moisture characteristics, particle size distribution, aggregate stability, organic carbon, available P, ammonium extractable Ca, Mg, and K, and field infiltration characteristics.

RESULTS

Soil physical properties

The trend in bulk density of the 0- to -15-cm layer increased with time under conventional tillage whereas it was relatively constant under no-tillage (Fig. 1). Bulk density increased from initial levels of 1.39 and 1.36 Mg m^{-3} in no-tillage and conventionally-tilled plots respectively to 1.38 and 1.54 Mg m^{-3} after 5 years of continuous cultivation. The trend in bulk density also increased relative to the length of conventional cultivation in the different tillage rotations with conventionally-tilled plots greater than those of C4N4, C2N2, C1N1 and C2N4 by 1.7%, 3.1%, 6% and 8%, respectively. Among cropping sequences, bulk density was lower under corn-cowpea and cowpea-corn rotations than under continuous corn or cowpea.

Wet-sieving (Table 1) as indicated by mean weight diameter (MWD) showed that stability of aggregates to water in the 0- to 15-cm layer significantly decreased along the tillage treatments NT, C2N4, C1N1, C2N2, C4N4, and CT and along the cropping systems of corn-cowpea, cowpea-corn, continuous corn and continuous cowpea. The trend was the same for the stability of the 0.10- to 0.25-mm aggregates. MWD of 1.25mm in 1982 was reduced by 40% and 60%, 2 and 5 years later, respectively under conventional tillage. The quantity and stability of the 0.10- to 0.25-cm soil aggregates were slightly but significantly (at 0.05 level) enhanced under corn-cowpea system.

Tillage not only reduced total porosity in the 0- to 15-cm layer as a result of changes in bulk density and aggregate size but also changed the pore size distribution even more drastically during the five years. In comparison with continuous no-tillage, the proportion of pores 50-μm radius which was 18% in 1982 decreased by 12%, 23.5%, 35, 46.5 and 57% in C2N4, C2N2, C1N1, C4N4, and CT. When averaged over 5 years, the C2N4 treatment had a significantly (0.05 level) higher total porosity (43%) and proportion of pores > 50-μm radius than the CT treatment (39.8%).

Compared to no-tillage, equilibrium infiltration rates decreased over 5 years from 18cm h^{-1} to 9.8, 5.0, 6.2, 3.8 and 2.5 cm h^{-1} in the C2N4, C2N2, C1N1, C4N4, and CT respectively. Infiltration was enhanced by cropping in the oder corn-cowpea cowpea-corn corn-corn cowpea-cowpea.

Plots under continuous no-tillage generally stored more water at any matric potential compared to those under continuous tillage. Available water holding capacity (difference between moisture contents at 0.01 and 1.5 MPa) was also higher under the no-tillage which increased from 10.5% in 1982 to 14.6% under no-tillage and 11.8% under continuous tillage, 5 years later. Among the tillage rotation treatments, available water holding capacity was highest for C2N4 (12.9%) and lowest for C4N4 (10.8%). Cropping sequence did not have a significant effect on soil water retention at > 40 - kPa matric potential but enhanced available water holding capacity of conventionally-tilled plots and those in tillage rotations.

Soil chemical properties

Organic matter cotent decreased from 3.58% in 1982 to 2.95 and 1.35%, 5 years later under no-tillage and continuous tillage, respectively with the highest rate of decline occuring within 3 to 4 years of cultivation. The rate of decline of organic matter varied with the length of tillage in a tillage rotation with the rate of decline more than twice as high during tillage (0.49%/season) compared to during no-tillage (0.22%/ season) during the first 2 years of cultivation. The rate of decline of organic matter content was higher under cowpeas than under corn because of smaller amount of residue turn-over (1 ton/ha/crop) for cowpea as compared to corn (6 to 8 ton/ha/crop).

Comparison of soil chemical analysis in 1982 with those of 1986 indicated significant decline in soil pH, exchangeable cations and CEC due to cultivation regardless of tillage treatment although the rate of decline was more drastic with tillage than with no-tillage. The changes in CEC and exchangeable cations were related to changes in organic matter content. Corn-cowpea system significantly increased levels of organic matter, exchangeable cations and CEC.

Crop Response

Performance of crops in terms of emergence and growth rate was better with NT and tillage rotation than under continuous tillage. Crop yields from 1982 are presented in Table II. Although there were seasonal variations in yields apparently due to rainfall distribution and tillage rotation effects, the trend indicated that yield per crop tended to decrease as the amount of tillage increased, with no-tillage having the highest yields. In some seasons, there were no statistical differences between no-tillage and C2N4 treatments. The mean yields for the tillage rotation treatments were 2.24 t ha^{-1} for corn and 0.68 t ha^{-1} for cowpeas which were greater by 30% and 22% respectively (at 0.05 level) compared to those of continuous tillage.

Corn and cowpea yields for C2N4 were 15% and 18% respectively less than those for continuous no-tillage over the 5 years of cultivation. The trend toward decreased yields with more tillage became less significant when corn and cowpea were grown in rotation than when continuous corn or cowpea system was used.

DISCUSSION

The above-observed deterioration in soil physical and chemical properties was early in the cropping period illustrating quite clearly the weak structure of the soil. Such observations were also made by Fauck et al., (1969), Moreau (1978) and Lal (1985) on some tropical soils. Correlation co-efficient for MWD with organic matter, 5 years after the initiation of the experiment was 0.68 which is significant at the 1% level suggests direct correlation between aggregate stability and organic matter as reported in a number of studies (Alegre and Cassel, 1986). The high rates of decline of organic matter under tillage readily explain the early deterioration of soil structure which was within 3 years of continuous tillage in this study.

Overall deterioration of the surface soil which was in the following order: CT $>$ C4N4, $>$ C2N2 $>$ C1N1 $>$ C2N4 $>$ NT reflected the differential lengths of soil disturbance and suggest that at least two years of no-tillage may be required to rejuvenate soil for each year of conventional tillage.

Effects of cropping systems on soil improvement reflected the differences in amount of residue turnover and decay rates of the different crops which would affect soil organic matter contents and aggregate stability. Corn produces about 6 times more residue per ha compared to cowpea and provides more surface cover and protection against aggregate breakdown.

The yield trends showed definite yield advantages for rotational tillage over continuous tillage and for sequential cropping over continuous corn or cowpeas reflecting the trends in the rates of soil deterioration under the different treatments.

CONCLUSIONS

1. Soil deterioration increased with length of conventional tillage along the tillage treatments NT, C2N4, C1N1, C2N2, C4N4, CT with no-tillage consistently associated with more favourable soil conditions, and higher yields.
2. Alternating one year of conventional tillage with two years of no-tillage in combination with corn-cowpea cropping system resulted in less soil deterioration and higher crop yields compared to continuous tillage, but less than 20% lower yields than no-tillage.
3. A cost-benefit appraisal of the tillage rotational system versus the continuous no-tillage for alleviating continuous cultivation problems is required.

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Table I:
Changes in selected soil properties in the 0- to 15-cm layer before (initial) and 5 years after tillage treatments were imposed.

Tillage Rer	O.M. %	Total Porosity m^{-3}	MWD mm	Infil. rate $cm\ h^{-1}$	Moisture retention (gg^{-1}) at indicated matric potentials (MPa): 0	0.003	0.04	0.1	0.3	1.5
Initial	3.48	0.49	1.25	42.0	39.2	30.4	12.8	9.2	6.1	4.9
				1986						
NT	2.95	0.47	1.19	18.2	37.9	32.6	13.7	8.5	7.9	6.2
C1N1	1.96	0.44	0.75	6.2	31.3	25.6	9.2	7.2	6.8	6.4
C2N2	1.89	0.43	0.68	5.0	29.9	24.5	9.9	7.5	6.9	6.2
C2N4	2.25	0.45	0.84	9.8	32.6	28.0	10.9	7.9	6.9	5.6
C4N4	1.85	0.42	0.62	3.8	29.2	22.1	11.0	8.3	7.6	5.9
CT	1.35	0.39	0.48	2.5	28.9	20.9	10.7	8.6	7.8	6.3

Table II
Grain yields (metric ton/ha) as affected by tillage rotation and cropping sequence for the first (1st) and second (2nd) seasons.

Cropping sequence	NT		C1N1		C2N2		C2N4		C4N4		CT		LSD (0.05)	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
							1982							
Corn-Cowpea	3.17	0.83	3.12	0.80	3.16	0.76	3.15	0.82	3.18	0.79	3.15	0.83	0.46	0.16
Cowpea-Corn	0.78	3.11	0.75	3.14	0.74	3.08	0.78	3.01	0.75	3.05	0.69	3.02	0.14	0.43
Corn-Corn	3.20	3.06	3.21	3.08	3.12	3.01	3.15	3.07	3.18	3.02	3.12	3.00	0.39	0.42
Cowpea-Cowpea	0.79	0.87	0.72	0.81	0.68	0.74	0.72	0.80	0.68	0.79	0.70	0.78	0.14	0.18
							1984							
Corn-Cowpea	3.08	0.82	2.56	0.71	2.64	0.68	2.74	0.76	2.39	0.63	2.24	0.65	0.23	0.10
Cowpea-Corn	0.70	2.98	0.62	2.44	0.66	2.62	0.69	2.57	0.58	2.21	0.53	2.18	0.08	0.18
Corn-Corn	2.96	2.87	2.18	2.07	2.51	2.32	2.42	2.29	2.23	2.14	2.03	1.95	0.19	0.23
Cowpea-Cowpea	0.72	0.79	0.57	0.59	0.62	0.68	0.59	0.65	0.56	0.58	0.52	0.56	0.10	0.12
							1986							
Corn-Cowpea	2.87	0.79	2.17	0.62	2.19	0.58	2.48	0.68	1.80	0.58	1.74	0.53	0.18	0.08
Cowpea-Corn	0.75	2.70	0.58	1.79	0.51	1.94	0.63	2.25	0.45	1.68	0.46	1.61	0.07	0.15
Corn-Corn	2.78	2.81	1.60	1.70	1.65	1.58	2.05	2.00	1.62	1.58	1.56	1.48	0.15	0.17
Cowpea-Cowpea	0.64	0.68	0.60	0.47	0.42	0.51	0.52	0.57	0.40	0.46	0.38	0.44	0.08	0.06

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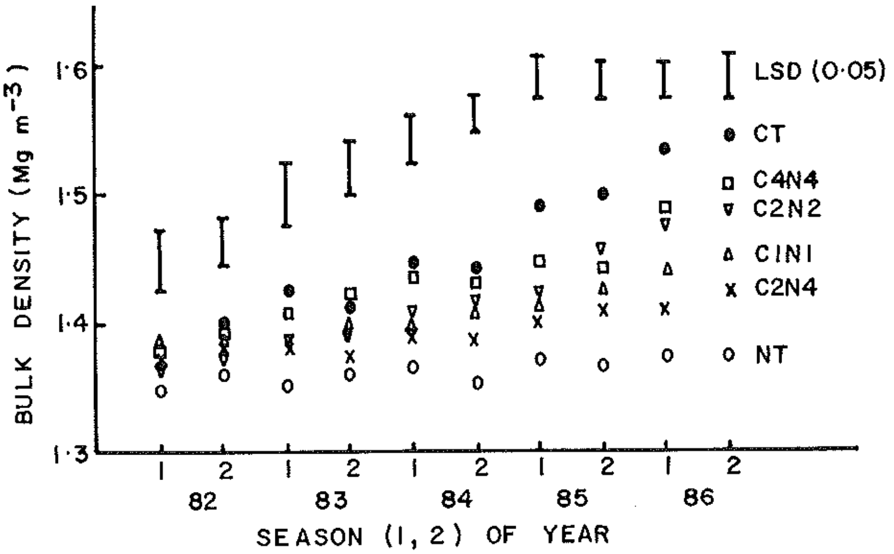

Fig. 1 : Bulk density for 0 - 15 layer at different seasons of year as affected by tillage rotation.

RESULTS OF TILLAGE TRIALS CARRIED OUT IN 1981-1987 IN CENTRAL ITALY

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ABSTRACT

Reduced tillage methods (shallow ploughing and chiseling, deep subsoiling + shallow ploughing, minimum tillage, zero tillage) were compared to traditional deep ploughing (.45 m for winter cereals, .55 m for summer crops) in a farm-scale experiment on heavy soil in Umbria (Central Italy). Only a few cases of significant yield differences were observed on wheat, mainly due to weed infestations or attacks of take-all. After 6 annual tillage cycles, soil profile characteristics and root growth resulted slightly affected by tillage methods even if penetration resistance was higher. The surface soil layer (0-5 cm) was improved by minimum tillage for O.M. content and some mechanical properties.

INTRODUCTION

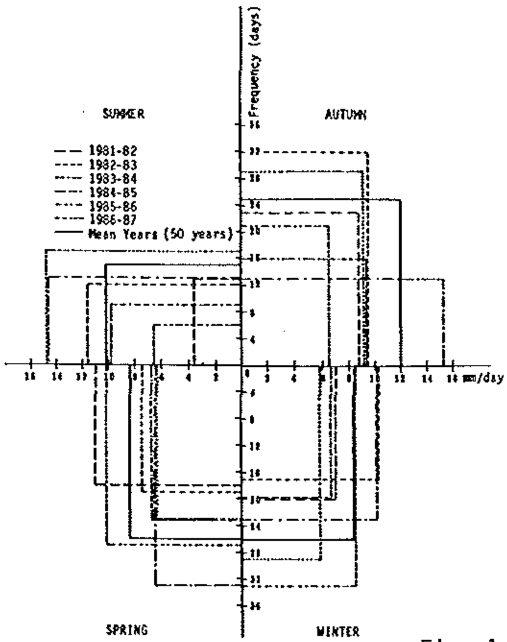
By the term "reduced tillage" we mean one or several mechanical operations for seedbed preparation with less input of farm machinery and/or energy and/or work time than with conventional tillage. The most important factors regarding the suitability of reduced tillage are the following: soil, climate, perennial weed infestation, crop and crop rotation. This paper presents the results of experiments conducted for six years on clayey soil (45÷50% of clay) to study various reduced tillage systems for winter cereals and sunflower. An additional experiment was established in 1986 for wheat, on the same soil, with direct drilling.

MATERIALS AND METHODS

In Italy tillage techniques have always been characterized by a great working depth (.45-.60 m), taking into account the peculiarities of the soil and the climate. Although deep ploughing seems to present advantages such as greater water reserve, better root elongation and better weed control, it nevertheless presents disadvantages such as soil layer inversion, large clod formation, organic matter dilution and high energy costs. Since 1981 several research project have been carried out to assess the suitability of the following alternative tillage methods:

1) minimum tillage;
2) shallow ploughing;
3) double layer tillage (*subsoiler plus shallow pluoghing*);
4) chiseling.

Data presented in this report came from tillage tests on a very large farm in Central Italy (700 ha on hills with 7-9% slope), located in a zone having humid, severe winters, one dry, hot summers. The mean annual precipitation generally reaches 850 mm, distributed mostly between November and April although there are some years with very low precipitation, even less than 600 mm, like 1981-82 and 1986-87 (Fig. 1).



The soil is a deep brown alluvium, rich in clay (45-50%) and with a subalkaline pH (7.8). The farm is divided into large sections with fields 30 m wide and 200-600 m long. Trials were carried out on some of these sections and each tillage method was used on at least three whole fields, each of which served as a replication, allowing a randomized block design to be used on a farm-size scale. Tillage comparisons were carried out as close in time to one another as possible in order to have the same soil conditions (with the exception of double layer tillage where the two operations were done at different times).

Fig. 1 - Seasonal rainfall polygons

Tillage methods

Winter cereals. - The following treatment were applied:
- deep ploughing (.45 m);
- shallow ploughing (.30 m);
- minimum tillage with disc harrow (.10 m);
- chiseling (.30 m).

Summer crops. - In our environment, characterized by scarse and irregular rainfall in the summer and by abundant precipitation in the winter deep tillage is considered to be an important means of conserving soil water. Hence, minimum tillage was not tried. The following treatments were applied:
- deep ploughing (.55 m);
- shallow ploughing (.30 m);
- double-layer tillage.

Double layer tillage was performed using two tillage implements at two different times: a subsoiler at a depth of .55 m on dry soil in order to obtain better breakage and a moulboard plough at a depth of .30 m with the soil in the best possible conditions. Trials were carried out on sunflower, lucerne and corn silage.

RESULTS AND DISCUSSION

Tillage methods were separately compared to traditional ploughing because they were not always done contemporaneously in all of the sections. All data are the means of six years results (Tab. 2, 3, 4 and histogram in fig. 9).

Crop response

Winter cereals. - Winter wheat is the crop of most interest: on average, over the six years, the different treatments gave slightly lower yields than conventional tillage, whereas minimum tillage equalled the yield after deep ploughing (Fig. 2). Results of treatments varied from year to year: the fluctuation of wheat yields are attributed to the variation in rainfall and other related biological factors. In 1982-83 the only detected difference was with wheat after sunflower and sugar beet: wheat with minimum tillage yielded more than that on ploughed plots. In 1982-83 the autumn was relatively wet, whereas the winter and the spring were dry. Among treatments, the lowest production was obtained with chiseling in 1983-84. This was due to stronger attacks of take-all disease, which was favored by the presence of straw on the surface. At times, varying degrees of weed infestation were observed wich seemed to be more influenced by the time of tillage than the type of tillage.

Summer crops. - In all years, no appreciable differences were obtained for sunflower production. Also, no differences were noted in lucerne and corn silage production; results of these crops are not reported because they refer to only one year.

Soil physical properties

After 6 annual tillage cycles the following observations were done: bulk density, soil moisture and cone resistance profiles. The results of 1985 regarding deep ploughing vs. minimum tillage are shown in fig. 3, whereas fig. 4 shows the wheat rooting density profile. Cone resistance and moisture content value for three treatments (ploughing to .20 m and to .40 m and minimum tillage) were measured in May and June 1986 (Fig. 5). In 1987, from 23/3 to 12/6, several measurements of penetration resistance and moisture content were taken. The mean values are reported in fig. 6 for the following tillage treatments: direct drilling, minimum tillage, ploughing to .30 m and to .45 m depth. Fig. 7 shows cone resistance and moisture content values for two treatments (deep ploughing vs. minimum tillage) at two different depths (.40 m and .20 m) as a function of time.

In general, for all the tests, bulk density, soil moisture and root density profiles show no statistically significant differences between treatments. Under minimum and zero tillage cone resistance was significantly higher. When moisture content was high, differences between cone resistance under various treatments were not statistically significant.

Chemical properties

Organic matter and soil compressibility. - Table. 1 shows that the top layer after minimum tillage contained more organic matter than after deep ploughing. Modification induced by O.M. on the compressibility of soil was observed using the Proctor Test (Fig. 8). The elasticity of the free organic fragments could explain the increase of the compactability resistance. Moreover higher values of Attemberg's plasticity limits are observed in the top layer with minimum tillage than in the top layer with deep ploughing (Tab. 1).

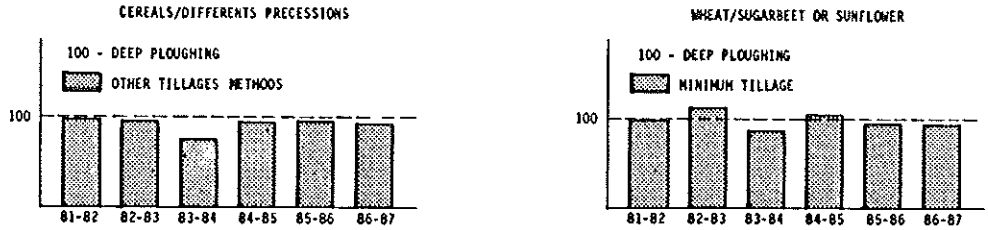


Fig. 2 - Yield results of winter wheat with reduced tillage, 1982-87.

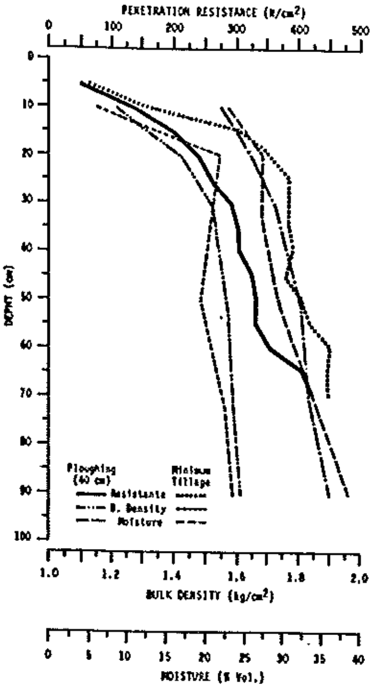


Fig. 3 - Penetration resistance, bulk density and moisture content profiles.

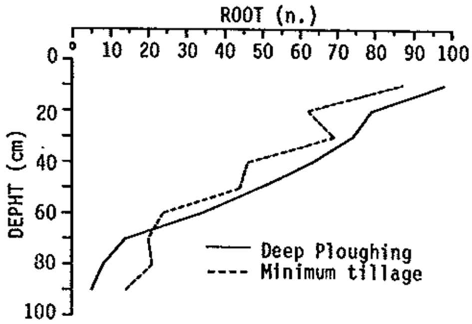


Fig. 4 - Root density profile. Root count from sections of 66.2 cm².

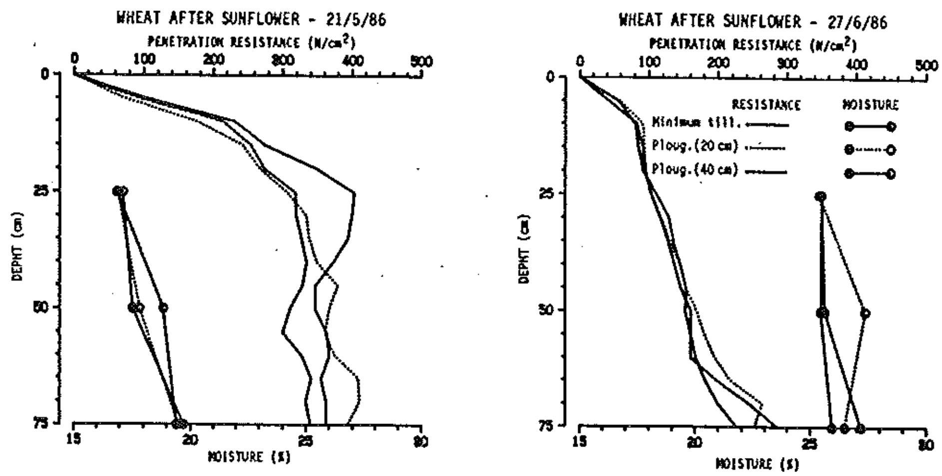


Fig. 5 - Penetration resistance profile on different dates.

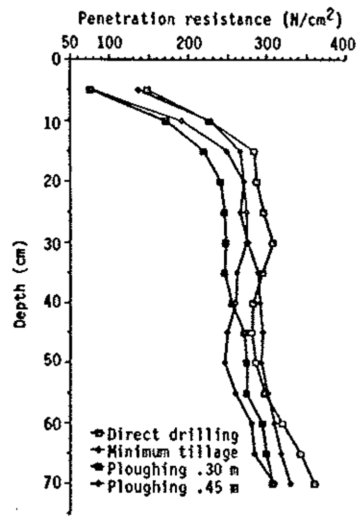


Fig. 6 - Penetration resistance and moisture mean values arter different treatments.

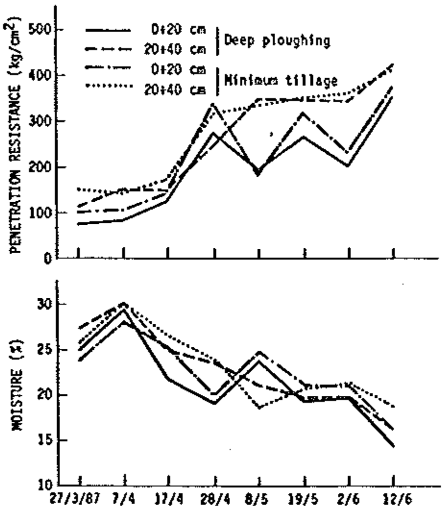


Fig. 7 - Penetration resistance and moisture content as a function of time.

SOIL TEXTURE LAYER 0÷5 cm

COARSE SAND %	FINE SAND %	SILT %	CLAY %
8,6	2,4	42,5	46,5

CHANGES IN SOIL PROPERTIES UNDER TWO TILLAGE METHODS (0÷5 cm)

	ATTEMBERG LIMITS L.L.	P.L.	ORGANIC MATTER
DEEP PLOUGHING	52	26	1.78
MINIMUM TILLAGE	59	29	2.68

Table 1

Field-work capacity and fuel consumption

All the data, reported in tables 2, 3 and 4, are illustrated in fig. 9. Minimum tillage on winter wheat, carried out with a disk-harrow, increased the field-work capacity more than 5 times with respect to deep ploughing; the increase with chiseling on barley was a little less than 5 times. With shallow ploughing the increase was 45% on winter wheat and 41% on barley. On summer crops the increase was 72% with shallow ploughing and 24% with double layer tillage.

TABLE 2 - Crop: winter wheat; previous crop: summer crop.
Six year means ± standard error.

Tillage methods.	Effective field-work capacity		Fuel consumption		Yield (standard moisture)	
	ha/h	% (*)	kg/ha	% (*)	t/ha	% (*)
Deep ploughing (.45 m)	.31 ± .01	-	72.2± 2.10	-	5.16 ± .07	-
Shallow ploughing (.30 m)	.45 ± .02	+45	47.9± 2.40	-34	4.98 ± .09	-3.5
Deep ploughing (.45 m)	.32 ± .01	-	70.0± 2.77	-	5.03 ± .12	-
Minimum tillage (.10 m)	1.97 ± .23	+516	14.7± 1.90	-79	5.05 ± .12	+0.3

TABLE 3 - Crop: barley; previous crop: winter wheat.
Six year means ± standard error.

Tillage methods.	Effective field-work capacity		Fuel consumption		Yield (standard moisture)	
	ha/h	% (*)	kg/ha	% (*)	t/ha	% (*)
Deep ploughing (.45 m)	.27 ± .01	-	78.9± 2.80	-	5.17 ± .14	-
Shallow ploughing (.30 m)	.38 ± .02	+41	51.5± 1.59	-35	5.11 ± .15	-1.2
Deep ploughing (.45 m)	.27 ± .01	-	78.9± 2.80	-	5.17 ± .14	-
Chiseling (.30 m)	1.59 ± .06	+490	13.1± 1.76	-83	4.68 ± .14	-9.5

TABLE 4 - Crop: sunflower; previous crop: barley.
Six year means ± standard error.

Tillage methods.	Effective field-work capacity		Fuel consumption		Yield (standard moisture)	
	ha/h	% (*)	kg/ha	% (*)	t/ha	% (*)
Deep ploughing (.55 m)	.25 ± .01	-	84.6± 2.80	-	2.39 ± .09	-
Shallow ploughing (.30 m)	.43 ± .02	+72	51.8± 1.44	-39	2.43 ± .10	+1.7
Deep ploughing (.55 m)	.25 ± .01	-	82.3± 3.09	-	2.43 ± .11	-
Subsoiler (.55 m) + Shallow ploughing (.30 m)	.31 ± .01	+24	68.8± 1.92	-16	2.38 ± .11	-2.1

(*) Percent differences with respect to control ("deep ploughing").

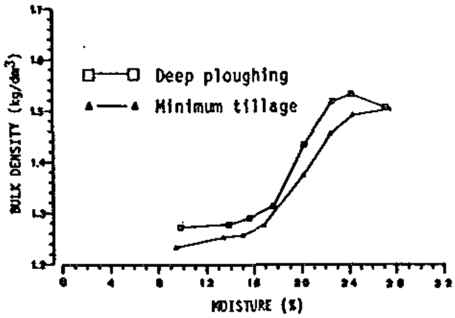


Fig. 8 - Proctor's compactability test.

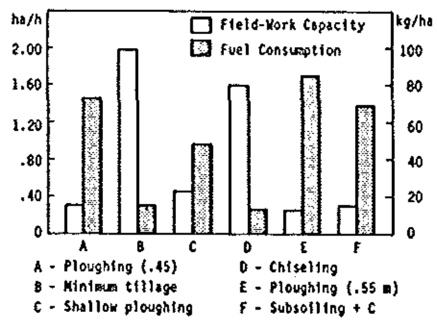


Fig. 9

CONCLUSIONS

This study demostrates that different reduced tillage methods may be used on clay soil; with respect to deep ploughing, they did not influence root system development, water balance and crop yield but they allowed a notable decrease in fuel consumption and an increase in field-work capacity. Furthermore, reduced tillage methods allow organic matter to be concentrated in the topsoil. Minimum tillage is a very important technique for winter cereals following summer crops which have residues that don't interfere with the use of common drills. Shallow ploughing can be a correction of traditional deep ploughing. "Double layer" tillage should be preferred to deep ploughing for non-irrigated summer crops, in order to break up the soil to great depths. Reduced tillage methods allow a better use of tractor power, increasing the width of tillage rather than the depth of ploughing. We intend to continue these trials in order to obtain a long-term verification on possible soil modifications.

EFFECT OF SEEDBED AND FERTILIZER ON SOIL HEAT FLUX, GROWTH AND DEVELOPMENT OF GRAIN AMARANTH (AMARANTHUS CRUENTHUS)

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ABSTRACT

Studies were made on the effect of three different seedbeds (ridge, raised and flat), nitrogen and phosphorus fertilizers on the soil heat flux growth and development of Amaranthus cruentus L. Seedbed and nitrogen significantly ($P = 0.05$) influenced plant height and root length of the crop. Lodging percentage was found to be least in the ridged seedbed and highest in the flat seedbeds. Phosphorus had very significant ($P = 0.01$) effect on the percentage dry matter of shoot and root of the grain amaranth. The net heat flux decreased with increased pulverization and was highest between 1100 and 1400 hours.

INTRODUCTION

Amaranthus cruentus produces 6.29g of lysine per 100g of protein (Michael, 1978) and using the nutritionist's scale of 100, amaranth grain has a biological value of 75 while cow milk and soybean have 72 and 68 respectively (National Research Council, 1984). Being nutritious, grain amaranth could be used to enrich traditional diets in developing countries.

The amaranth grows erect rapidly, requiring good soil and moderate rainfall. Earlier studies (Olufolaji, 1985) revealed that at maturity three types of lodging (root 11%; stem 38%; inflorescence 29%) were prevalent when grown in the early season (April - July). Stem lodging was thought to be caused by high planting density which restrict light and reduce stem firmness on one part and by increased leaf formation stimulated by nitrogen on the other. Either way the thermal energy in the soil and therefore the temperature conditions in the soil are affected. And sensible heat flux between the air and the ground is an important element in the surface energy balance (Schieldge, 1978). Fasheun and Ibe, (1986) working with Amaranthus hybridus at Ibadan, Nigeria, found its energy conversion efficiency to be 10.9% while Kassam and Kowal (1975) found for millet (another grain) at Samaru, Nigeria, that soil heat flux accounted for only 6% of total dry matter produced. Mean soil heat flux is also known to affect soil moisture retention (Fasheun, 1986).

Since tillage adequately loosens the soil for root growth (Aina, 1979) to provide anchor for the plant, increases soil water content, enhances infiltration, reduces soil temperatures and affects the nutrient status of the soil (Black, 1970; Simpson and Gumbs, 1985), this study was carried out to determine the major causative soil factors that predispose the crop to lodging. And also to relate crop yield to seedbed method vis â vis soil heat flux.

MATERIALS AND METHODS

The experiment was carried out at NIHORT, Ibadan, Nigeria. The soil is sandy loam, fine textured, free draining, consisting of 65% sand, 22% silt and 13% clay, with medium acidity (pH 5.6), low percentage of organic carbon (1.03) and total Nitrogen (2.92). The available phosphorus and extractable potassium were 4.65µg/gm and 86µg/gm respectively.

The three land preparation treatments received a single pass of the disc plough, (20 - 25cm depth) followed by a single pass of the harrow. The ridged seedbed (RD) was ridged to a height of 20 - 25cm while the raised (RB) was bedded to a height of 10 - 15cm. The flat seedbed (FL) did not receive any further pass of a tillage equipment. Grain amaranth seeds were drilled at the rate of 2.5 $kgha^{-1}$ in two rows in plots 2m x 2m spaced 1m apart. Plant population was maintained at 90,000 plants ha^{-1} in each plot after seedling emergence and establishment.

Nitrogen and phosphorus at three levels (N = 0, 60, 120 $kgha^{-1}$ and P = 0, 30, 60 $kgha^{-1}$) were applied in-between the rows in two equal installments at 4 and 8 weeks after planting (WAP). Potassium (K = 22.5$kgha^{-1}$) was given to all plots at 4 WAP. The split-plot design was replicated four times. Heat flux transducers were installed face up in all plots at a depth of 5.0cm. Heat flux meters were used to measure the inflow of the sun's energy conducted into the ground from sunrise to sunset at specific days and at 0900, 1200 and 1500 hours daily.

The plots were kept weed free and sprayed with Dithane M45 (2% mixture) forthnightly. Growth and yield parameters of the crops were monitored.

RESULTS

Table I shows that plant height increased significantly (P =0.05) with increasing levels of N and soil pulverization. Root length, seed dry weight and inflorescence dry weight were significantly influenced by the three treatment factors. However, while only seedbed influenced lodging, phosphorus and all the treatment interactions influenced percentage dry matter (%DM). RD and RB increased seed weight significantly. Seed weight increased as N increased from 0 to 60 $kgha^{-1}$ and P from 0 to 30 $kgha^{-1}$. Beyond these fertilizer levels, there was a general decline in seed yield. Inflorescence fresh weight was not affected by tillage but by N and P in all tillage treatments.

Fig. 1(a) shows that both ground conduction and net hemispherical radiation were symmetrical at 1100 and 1300h respectively; while heat flux is symmetrical about 1200h for all tillage and fertilizer treatments. The heat fluctuation in the soil in the course of a day in the life of the plant is shown in Table II.

DISCUSSION

RD and RB increased plant height and root length and decreased percentage lodging. Soil pulverization may have enhanced root development affording the plant a better anchor than FL since inflorescence fresh weight which could predispose the plant to lodging was not significantly affected by tillage. Nitrogen and phosphorus levels increased plant height and root length but both have contrasting effects on lodging and therefore their overall effects on lodging percentage were non-significant while increasing seed weight significantly (Table I).

More heat energy seem to be conserved in FL while RD lost more heat energy. The increased exposed surface area in RD more than in RB and FL may have been responsible for this. Furthermore, heat transfer rate by the tillage treatments seem to have occured more when the net radiation was highest. The range of peak heat flux was 1100h - 1400h for RD; 1000h - 1480h for RB; and 0900h - 1500h for FL. This shows that the rate was slower in FL and fastest in RD. Since RB is not significantly different from RD in terms of seed weight and lodging percentage and the heat transfer rate for RB seems slower for RD, production of the crop may be more profitable in the RB seedbed.

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Table I: Effects of Increasing Levels of Nitrogen and Phosphorus and seed bed on the Growth and Yield of Amaranthus cruentus L.

Treatment		Fertilizer Rate Kgha^{-1}	Plant Height (m)	Root Length (cm)	Lodging (%)	Dry Matter (%)	Seed Weight (tha^{-1})	Inflorescence Fresh Weight (tha^{-1})	Inflorescence Dry Weight (tha^{-1})
FL	N	0	1.06	20.4	54.6	21.1	1.68	3.95	0.85
		60	1.34	23.6	58.9	20.2	2.30	5.45	1.26
		120	1.26	21.1	63.2	24.0	2.08	4.58	1.07
	P	0	1.07	19.9	60.3	23.3	1.87	3.29	1.35
		30	1.24	20.6	51.2	25.9	2.49	4.47	1.56
		60	1.38	21.0	55.7	24.2	2.21	3.40	1.47
RB	N	0	1.35	24.4	45.5	24.4	2.03	3.20	1.14
		60	1.58	26.3	40.5	23.7	2.70	5.01	1.49
		120	1.50	29.4	42.2	21.8	2.35	4.87	1.51
	P	0	1.31	22.0	40.1	24.7	2.14	3.35	1.62
		30	1.34	24.9	33.1	18.3	2.73	3.93	1.77
		60	1.27	27.2	45.4	21.2	2.66	4.60	1.95
RD	N	0	1.31	28.5	54.6	23.8	2.06	2.96	1.26
		60	1.58	34.2	40.7	21.9	2.60	4.45	1.35
		120	1.59	33.9	38.9	22.9	2.72	4.26	1.35
	P	0	1.28	29.2	37.7	21.3	2.32	3.67	1.33
		30	1.33	31.8	34.8	18.9	2.81	4.79	1.68
		60	1.32	32.0	40.5	16.8	2.55	4.75	1.97
LSD(0.05)		All Treatment	0.08	2.13	6.11	1.19	0.13	0.35	0.28

Table II: Heat Flux (Wm^{-2}) Changes During a Day in the Growth and Development of Amaranthus cruentus L.

	Ridge	Raised Bed	Flat Bed
0900 hrs	+ 1192	+1258	+ 1094
1200 hrs	- 435	+ 375	+ 523
1500 hrs	- 960	- 995	- 705
Total	- 203	+ 638	+ 912

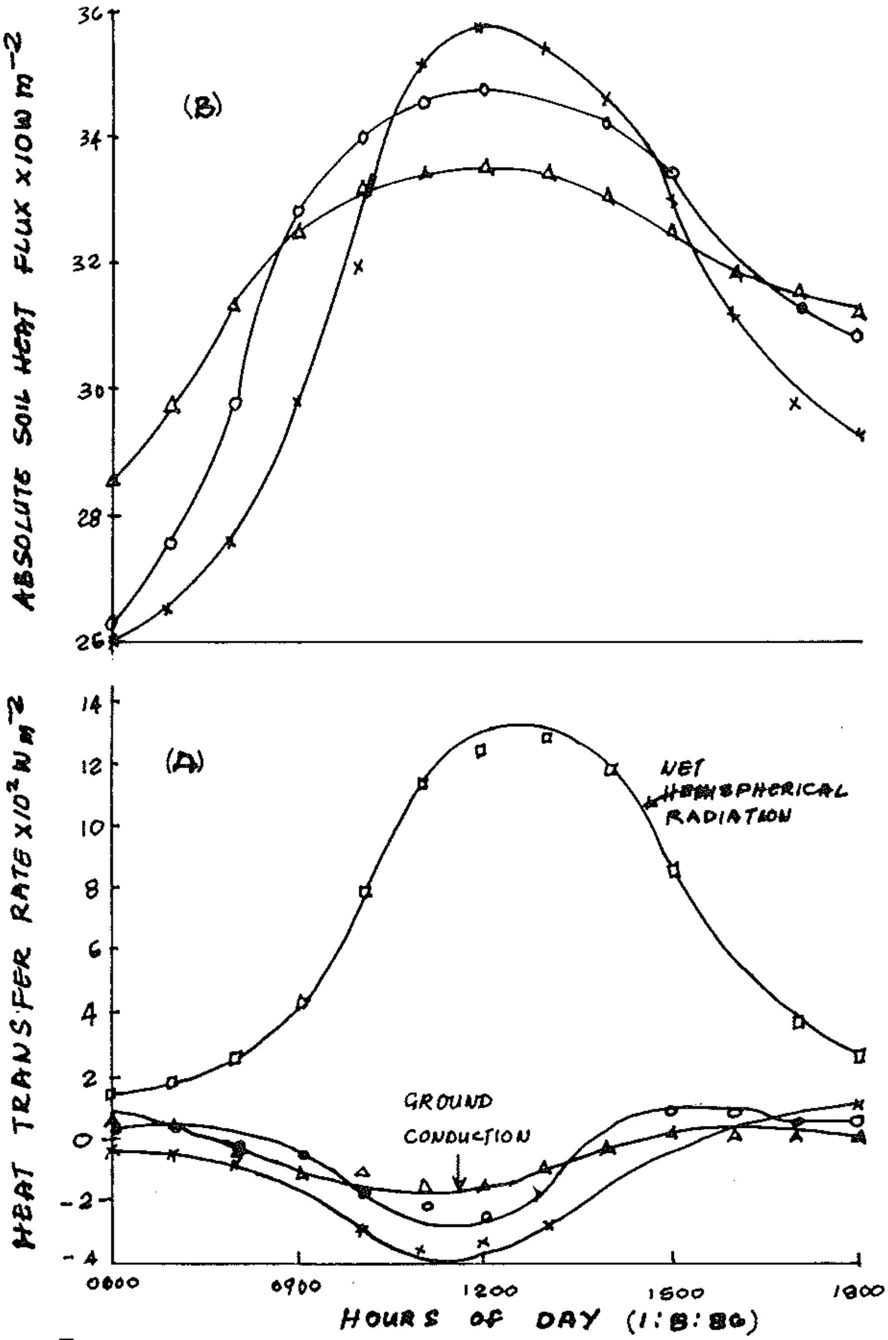

Fig I NET HEMISPHERICAL RADIATION (□—□), GROUND CONDUCTION FOR RIDGE (X—X) RAISED BED (O—O) AND FLAT BED (Δ—Δ) AND ABSOLUTE SOIL HEAT FLUX.

DIFFERENTIAL PERFORMANCE OF CASSAVA (MANIHOT EXCULENTA CRANZ) PLANTED ON THE RIDGE, FLAT, FURROW AND MOUND

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ABSTRACT

Field studies were conducted on a sandy soil in the woodland savana zone of Nigeria, to investigate the effect of the common tillage practices (planting on the furrow, mound, ridge and flat) on growth and yield of cassava over a 15-month period.

The percentage number of sprouted cuttings that survived to maturity were highest on the mound. The order of tuber yields on the different cultivation practices is furrow > mound > ridge > flat. The soil in the furrow (i.e. subsurface 15-30 cm) is richer in clay and CEC, than the sandy surface. This probably explains the superior performance of crops planted on the furrow than by any other tillage practice.

INTRODUCTION

Cassava (Manihot exculenta Cranz) is widely grown in the humid tropics, where it is an important staple food, as well as an important raw material for the manufacture of starch, carbohydrates and livestock feed.

Various tillage methods are employed in the cultivation of the crop throughout the tropics. The most frequently used of the various method of seed bed preparation in Nigeria being planting on the ridge, mound, furrow and on the flat (Onwueme 1978). Although much is known about the fertilizer requirements of the crop in Nigeria (Okeke et al 1982; Gurnah 1973), research efforts are not yet directed to linking the various tillage practices with growth performance and yield of the crop.

Similar information links are still needed on the effects of various tillage methods on length and conformation of the tubers as these are very important determinants of (1) the amount of tubers damaged during harvesting which reduces storability, (2) energy requirement for harvesting and (3) the ease of mechanical peeling and grading of the harvested tuber.

This paper therefore reports on the effects of various tillage practices on the practices on the performance of cassava on the field. The paper suggests a tillage method for cassava cultivation on leached sandy soils.

MATERIALS AND METHODS

The experiment was carried out over a 15-month period in the moist woodland savana in Ochaja, Nigeria ($7^{o}30'$N, $7^{o}15'$E) on a deep, non-gravelly silty soil derived from colluvial and alluvial materials.

Table 1 shows some physical and chemical characteristics of three horizons of the soil profile.

The layout of the experiment is randomised complete block with 4 replications. There are four treatments; planting on the ridge, flat, furrow and on the mound. Mounds are heaps made by gathering surrounding top soil to make a small hill. The operation is carried out with a hoe. Cuttings of approximately 20 cm from mature healthy stem of a recommended variety, 60444 were planted at 1 x 1 m spacing on the flat, on long ridges and on mounds which are both spaced 1 x 1 m apart. The mounds have a base diameter of 50 cm and a height of about 18. The last method of planting is on the furrow which is the depression between two ridges. Each sub plot (receiving tillage treatment) consists of 160 plants spaced 1 x 1 m apart in each of the seed bed type. There are 16 sub plots altogether in the four treatments x four replicate design.

Clean weeding with hoe is carried out 4 times in all. At harvesting, stand density in each sub plot was recorded. The total number of tubers and yield in ton/ha were computed for each sub plot harvest and the average length was taken.

RESULTS AND DISCUSSION

Tillage effects on growth

Table 2 shows that the method of seedbed preparation greatly affected growth of seedlings and invariably, the number of seedlings that survived to maturity. The number of sprouted cuttings that were carried to maturity was highest on the mound than on the ridge, furrow and flat respectively. Mound soil contain more mineralised nutrients since mounds are made by gathering fertile top soil from the surrounding area to make a heap (Onwueme 1978). Thus the initial higher soil nutrient concentration on the mound than on the ridge and furrow afforded the seedlings on this treatment an initial better start than those on other treatments.

Tillage effects on tuber yields

Table 3 shows the tuber number and fresh tuber yields on the different tillage practices. The order of fresh tuber yield (t/ha) on the different tillage methods are:

Furrow = mound $>$ ridge $>$ flat

Despite the significantly higher number of surviving plants in the mound treatments (Table 2), yet the overall yield was higher in the furrow treatment than in the mound, ridge and on the flat (Table 2). Thus each surviving plant yielded higher on the furrow than each surviving plant in other tillage treatments. In this excessively drained (colour of the 30 - 45 cm horizon being 2.5 YR 3/6) silty soil migration of clay to the subsoil is prevalent (Table 1), with the attendant leaching of important soil nutrients into the subsoil. Sequel to the higher clay content of the subsoil, moisture retention is also higher in the subsoil than in the top soil (Table 1). Planting on the furrow (the depression between two ridges) corresponds to planting on the 15-30 cm horizon which is richer in clay and is more water retentive than the top soil.

The phenomenon of the furrow soil being richer in clay and nutrients through process of leaching of bases and clay migration, and consequently being more water retentive, is the cause of the better performance of cassava on the furrow than on all other tillage treatments on soil type.

Tillage on length, number and weight of each tuber

On this loose silty soil, mechanical impedence to root/tuber penetration seems not to constitute a deterent to tuber elongation. Consequently, further soil loosening by cultivation has no advantageous effects on tuber length (Table 2).

The average weight of individual tuber is highest in the plants grown in the furrow probably because of the higher nutrient and water status of this horizon as previously discussed. Plants on the furrow treatment have slightly higher number of tubers per plant than in all other tillage treatments.

The effect of cultivation in exposing the rich and water retentive horizon that can better support plant growth seems to be the phenomenon underlying the differential effect of cultivation on yield of cassava on this alfisol.

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Table 1. Physical and chemical properties of some horizons of the soil profile in this investigation

Depth (cm)	Mechanical Analysis (%)			Soil Colour		Moisture retention %			Org. C (%)	CEC (me/100g)
	Sand	Silt	Clay	Dry	Wet	0.3 bar	15 bar	PH		
0-15	24.3	70.1	5.6	5YR4/3	2.5YR2/4	8.7	2.3	5.4	0.68	1.87
15-30	13.3	67.1	19.6	2.5YR3/6	2.5YR3/4	14.7	6.4	5.5	0.41	4.32
30-45	9.3	67.1	23.6	2.5YR3/6	2.5YR3/4	15.9	7.7	5.5	0.32	5.41

Table 2. Effect of tillage on yield and yield components

Tillage	% Plant survival	Tuber number	Tuber Wt ton/ha	Average tuber length	Average wt per tuber	Tuber number per plant
Mound	58.6	19218.8	9.94	36.4	517	3.29
Ridge	40.6	18862.5	8.59	35.0	456	4.79
Furrow	40.0	18893.8	10.10	35.2	535	4.80
Flat	25.8	10925.0	5.52	34.2	505	4.32
SE	5.73	2256.3	0.99	1.2	25.6	0.48

REDUCED TILLAGE AND STRAW INCORPORATION FOR WINTER BARLEY

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ABSTRACT

Disc plus tine cultivation, shallow rotary cultivation and shallow ploughing were investigated as quick and cheap alternatives to conventional ploughing, with or without pre-mixing, for straw incorporation in continuous winter barley on a gleysol in Scotland. Where straw incorporation was shallow, seed were broadcast instead of drilled.

Shallow incorporation in comparison to deep incorporation by normal ploughing made the crop more susceptible to damage by compaction and poor drainage. There was no evidence of any build-up of compaction in any treatment over the three seasons. However, with shallow incorporation, the favourable temperature regime in the straw layer and the increased aggregate stability associated with a build-up of organic matter over the three seasons may offset these problems.

INTRODUCTION

There is an increasing need to incorporate straw not only as a means of disposal but also to improve soil structure and conservation. Incorporation of straw may result in improved structure and drainage (Cannell, 1987). In this long-term field experiment previous treatments applied after straw burning indicated that, after three years, soil structural stability under conventional ploughing was less than under direct drilling or reduced tillage (Ball and O'Sullivan, 1987). One of the main objectives of the experiment reported here was to identify any long-term changes in soil structure associated with contrasting incorporation methods. Reduced tillage allows quick straw incorporation which is of particular value for winter cereals where there is a short period between harvest and sowing of the subsequent crop. This paper reports the yield and some of the soil physical properties measured in the first three seasons of the experiment with the emphasis on description of soil structure.

MATERIALS AND METHODS

The experiment was located 10 km south of Edinburgh, Scotland. The topsoil is a clay loam overlying a slowly permeable clay loam and is classified as a gleysol (FAO-UNESCO,1974). The average annual rainfall is 866 mm with a relatively large amount (269 mm) received in the three-month period of July to September when harvest, cultivations and sowing occur. This combination of soil type and climate makes such operations difficult to achieve without soil damage. Further details of the site, soil and climate are given by Ball and O'Sullivan (1987).

The ten experimental treatments, summarised in Table 1, were combinations of two residue, seven incorporation and two sowing treatments and were tested in four replicates. Mean grain yields for the three seasons are included in Table 1.

TABLE I Incorporation treatments and average grain yields.

	Residue Treatment	Incorporation Treatment	Sowing Treatment	Mean Grain Yield 1984-87 t/ha
1.	Straw + stubble	Plough 200 mm	Drill	6.7
2.	Stubble	Plough 200 mm	Drill	6.1
3.	Straw + stubble	Rotavate 70 mm+ Plough 200 mm	Drill	7.1
4.	Straw + stubble	Plough 200 mm	Broadcast	6.9
5.	Stubble	Plough 100 mm	Drill	6.3
6.	Straw + stubble	Rotavate 70 mm+ Plough 100 mm	Drill	7.1
7.	Straw + stubble	Rotary dug	Drill	6.8
8.	Stubble	No tillage	Broadcast	5.6
9.	Straw + stubble	Rotavate 70 mm	Broadcast	6.2
10.	Straw + stubble	Disc + tine	Broadcast	6.2

In the first season, treatments 4 and 7 were preceded by early disc plus tine incorporation and by early rotavation, respectively.

The straw plus stubble treatment consisted of combine-chopped straw (average length 150 mm) spread over a stubble of 100 - 150 mm length. The straw was removed from the stubble treatment by baling.

The incorporation treatments were chosen to give a range of depths of burial of straw and a range of degree of spread with depth. Rotavation was with an L-bladed rotor to 50-70 mm depth. Disc plus tine cultivation was with semi-inverter tines penetrating to 200 mm preceded by a row of discs. Rotary digging was with an L-bladed rotor to 100 mm depth followed by tines to 200 mm depth. Ploughing to 100-120 mm was with a purpose-designed shallow plough. Ploughing to 200 mm was with a conventional plough modified by the removal of skimmers and fitment of trashboards.

The sowing treatments were either conventional single-disc drilling or broadcasting. Seed were broadcast on treatments containing much surface straw in order to reduce the risk of drill coulter blockage and seedbed compaction. Seed were broadcast with a pneumatic boom fertiliser spreader and incorporated by rotary cultivation.

With the exception of the first season, no autumn nitrogen was applied, though spring nitrogen rates were increased to 10% above the level recommended by the East of Scotland College of Agriculture. The arrangement of the experimental plots allowed sprays, seed and fertiliser to be applied over the whole plot area at 12 m spacing using one pair of wheeltracks per plot.

Grain yield and soil physical properties were measured using standard techniques developed or modified at SCAE.

RESULTS

There was no yield advantage of ploughing deeper than 100 - 120 mm (Table 1). The average yield advantage of incorporating chopped straw plus stubble rather than stubble only was 0.66 t/ha. Incorporation by ploughing or rotary digging yielded more than non-ploughing systems. The average yield advantage of broadcasting over drilling where straw plus stubble were ploughed to 200 mm was 0.24 t/ha.

Soil results are confined to those treatments with contrasting depths of incorporation and, in most cases, the reference treatment of stubble ploughed to 200 mm. The organic matter content (Fig.1) of the top 200 mm of soil after three years' incorporation of straw and stubble by conventional or shallow ploughing increased slightly in comparison to ploughing stubble. Rotavation and, to a lesser extent, shallow ploughing tended to concentrate the organic matter near the surface.

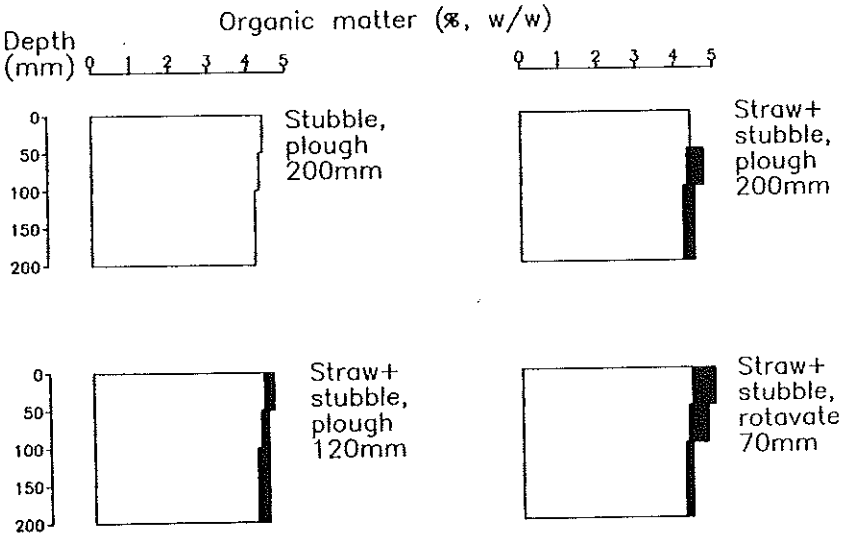

Fig. 1. Organic matter content of the topsoil in July 1987. The increase from the stubble, plough 200 mm reference treatment is shown in black.

The soil water content on the wettest occasion of measurement in 1987 (Fig.2) shows that the ploughed straw plus stubble treatments were drier than the the ploughed stubble and the more compact rotavated straw plus stubble treatments.

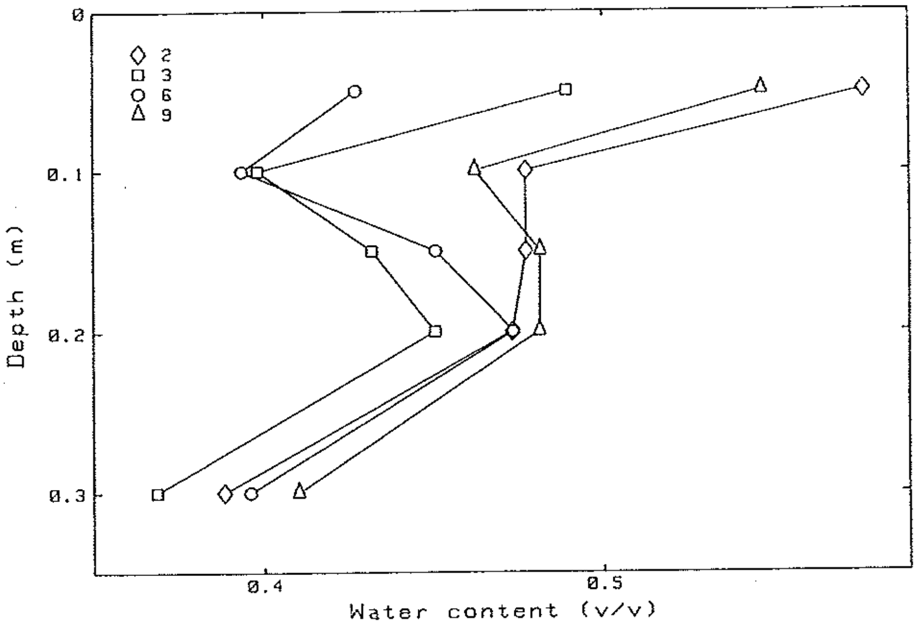

Fig. 2. Soil water content when wettest in Spring 1987. The numbers here and in Figs. 3 and 4 refer to the treatment numbers given in Table I.

Dry bulk densities (Fig 3) were not significantly different to those measured in the first season, indicating that straw incorporation had no effect on compaction other than by depth of tillage.

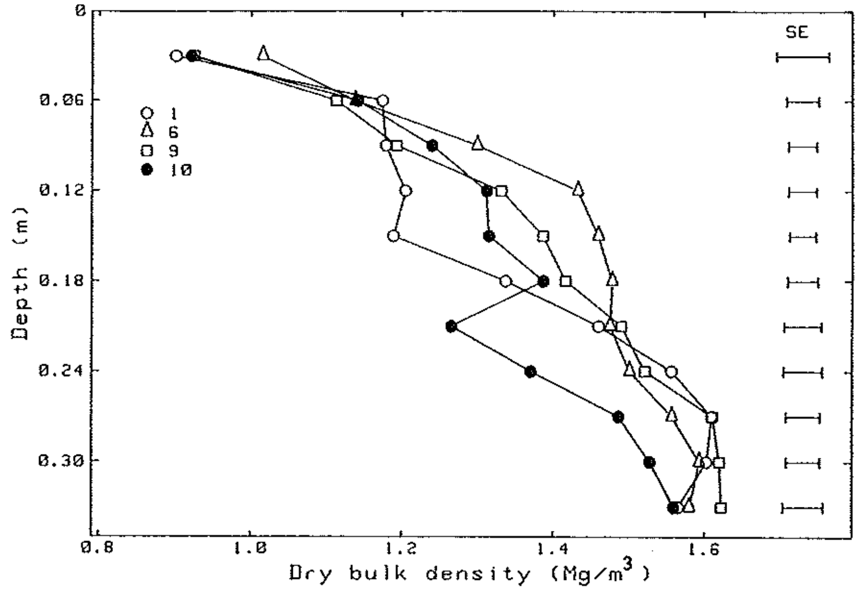

Fig. 3. Dry bulk density in July 1987.

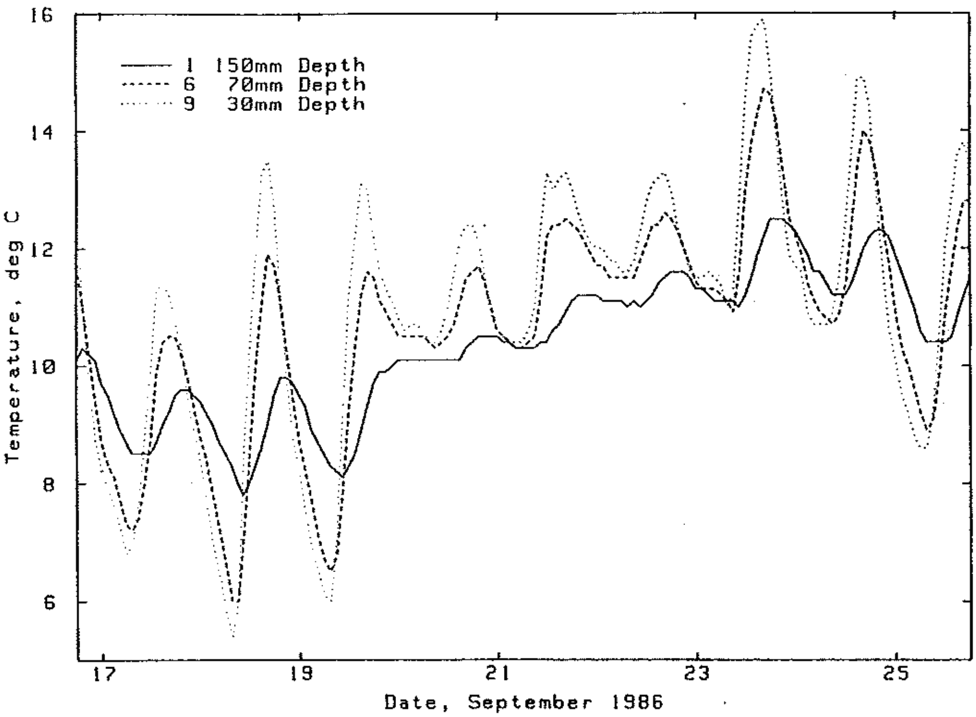

Fig. 4. Soil temperature in straw layers in the ten day period after sowing

Root resistance was considerably less than penetrometer resistance, although rotation lowered the ratio of penetrometer:root resistance to a value of between 2 and 4. Control root growth rates of 1.2 and 1.8 mm/h were measured with roots grown at constant temperatures of 21 and 24°C. These values were chosen to bracket the range of temperatures experienced by roots growing into the cores. Thus soil resistance reduced root growth rate to somewhere between 50 and 90% of the control. However Goss (1977) reports a reduction to 70% in root growth rate of maize in cells of ballotini to which a pressure of only 0.025 MPa was applied, which is less than one tenth of the root penetrationi resistances given in Table III. The apparent contradiction between our results and those obtained in experiments with ballotini is removed if it realised that the pressure confining the ballotini was about ten times less than that required to expand a cavity within the ballotini (Richards and Greacen, 1986; Bengough and Mullins, 1988).

CONCLUSIONS

(1) A large fraction of penetrometer resistance is frictional and may not be experienced by a plant root.

(2) Friction can account for much but probably not all of the difference between root resistance and penetrometer resistance.

(3) Root elongation rates were reduced by much less than is to be expected from experiments performed in pressurized cells of ballotini if the external pressure on the ballotini is considered equal to the pressure on the root but the latter proposition is now considered suspect.

ACKNOWLEDGEMENT

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MEASURING EFFECTS OF TILLAGE IMPLEMENTS ON SOIL SURFACE GEOMETRY WITH A LASER RELIEFMETER

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ABSTRACT

This paper describes a new optical technique for measuring in situ soil surface roughness parameters using a Laser reliefmeter. The method is based upon the defect-of-focus of a Laser light beam. Laboratory and field tests were carried out in order to improve this method for field use and to compare this technique with a method of reference. This technique is considerably quicker, causes no disturbance in soil. The degree of resolution and accuracy are satisfactory.

INTRODUCTION

Measurements of agricultural soil surface roughness parameters have been recorded to obtain quantitative data relating to different topics concerning :

i/ overland flow or slaking models of soil surface changes due to rainfall (Podmore and Huggins, 1980, Boiffin, 1984),
ii/ tillage effects on agricultural vehicule trafficability (Hunter, 1979)
iii/ microwave backscatter behavior of bare soil in active remote sensing (Ulaby et al., 1978)

Most of the reliefmeter are able to give a two dimensional recorded profile of height measurements. A three dimensionnal description of the soil surface roughness is obtained by translating automatically the reliefmeter at a choosen space increment and making replications of the profile measurement.

Automated reliefmeter generally consists of a horizontal frame (length = 1 or 2 m) with a laterally moving carriage. The probe is supported with the carriage. It consists of one pin which can be automatically moved in contact with soil. A sensor is able to provide a minimum impulse pressure on the soil surface and to record the height measurement. This kind of apparatus can have a small horizontal and vertical resolution ($\leq$ 0.001 m). But the needed time recording can be very long ($\geq$ 30 minutes) specially due to the carriage and pin translations.

Optical techniques have the great advantages to be quicker and non destructive with no mechanical contact between the sensor and the soil. Generally, the illumination source is a infrared Laser (Power $\leq$ 0.010 W) . The SELCOM technique which is available for measuring soil surface parameters of road (Brillet, 1985) cannot be used for agricultural field use. This paper contributes to show the interest of the defect-of-focus method.

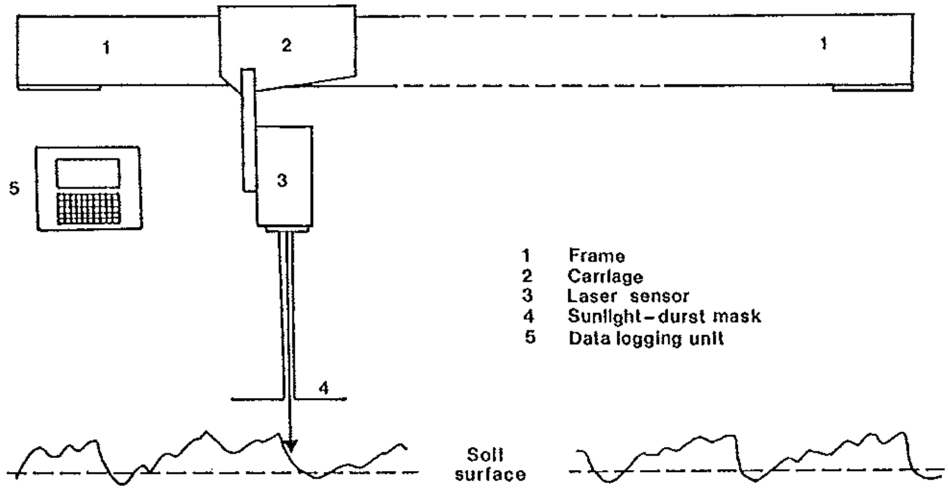


Fig. 1. The Laser profilometer

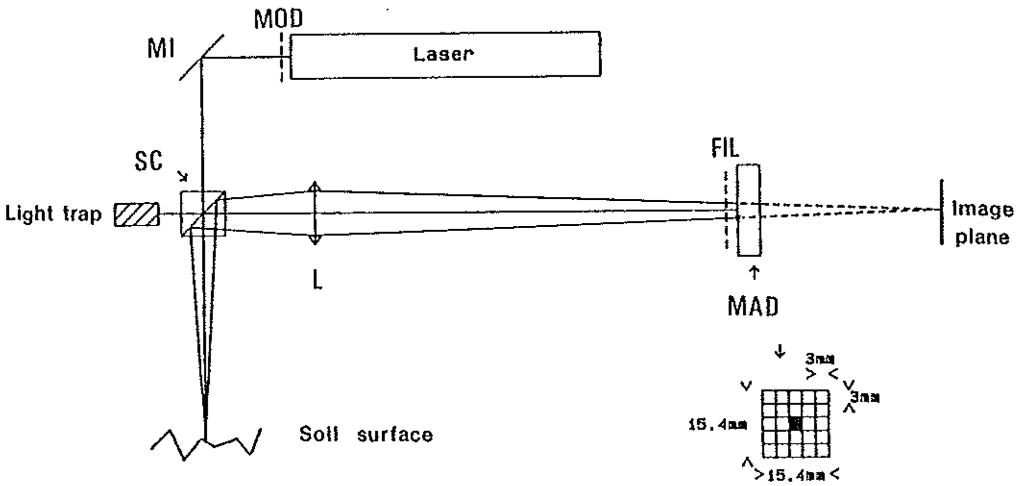


Fig. 2. The Laser sensor

MATERIALS AND METHODS

The Laser reliefmeter

The equipment is developped at the Laboratoire des Ponts et Chaussées (LCPC), Paris, France, in collaboration with the Institut National de la Recherche Agronomique (INRA), Soil Science Laboratory, Montfavet, France, for agricultural field use.

The main characteristics of the Laser reliefmeter are presented in Fig. 1. The Laser reliefmeter constists of an aluminium frame (2.5 m E.L.) which can be folded up for storage and transport. The Laser detector is supported with an aluminium carriage which can be automatically mooved along the frame. Traversing the carriage is done by means of an electrical motor and a rack-trail located along the frame. An angle-gap system is located upon the electrical motor in order to sample measurements at a constant increment. This equipment is linked by cable to a drive-data logging unit in conjuction with a portable micro-computer by the built in RS 232 interface. The micro-computer manages traversing functions of the carriage and data logging.

The main characteristics of the Laser sensor are presented in Fig. 2. The illumination source is a 0.010 W Helium-Neon Laser. The incident light beam is projected on the soil by means of the miror (MI). The return lignt beam is deflected into the lens (L) by the separator cube (SC). The light intensity is measured by the matrix-array detector (MAD) of 5 x 5 element-square matrix of photo-diodes (0.003 m x 0.003 m) which is located between the lens and the image plane of the exploration spot of the soil. The incident light beam is modulated (MOD) and the return light beam is filtered in order to minimize sources of bias measurement coming from illumination or color variations of the soil.

Principle of the defect-of-focus optical method

The exploration spot, in the vertical plan of the matrix-array detector gives a defect-of-focus image of the soil. In this plan, the spot size and the light intensity distribution across the spot vary with the asperity depth. The total light intensity (It) is measured by all the cells of the detector. The referenced light intensity (Ir) is measured by the central cell. It can be theoritically schown that the ratio (Ir/It) is related to the variation of the soil roughness (Gorecky et al., 1983, Caussignac and Morel, 1987). The available range of roughness depends on the geometrical characteristics of the optical mounting and the focal of the lens. For agricutural field use, two ranges of roughness were selected (± 0.050 m , ± 0.100 m , in relation to the mid-focal plane). Changing the range of roughness is made by changing the lens with wide (± 0.100 m) or small (± 0.050 m) focal length.. This choice depends on the roughness characteristics of the sampled profile. The measured profile leads to 1001 sampled values (Volt, range 0 - 10 Volt) of the surface height profile, at a constant increment of 0.002 m, registred automatically on the micro-computer. The 0.002 m increment was choosen according the size of the Laser spot.

Calibration procedure

An empirical calibration is made in laboratory using a tilted rule with two faces painted in white and black. Results of calibration procedure depend on the choice of tne lens. For the two lenses, a satisfactory analytical solution is obtained by fitting experimental data with a 5 degrees polynomial regression. Fig. 3 gives an example for the wide focal lens (± 0.100 m) of the relationship between the Laser measurements

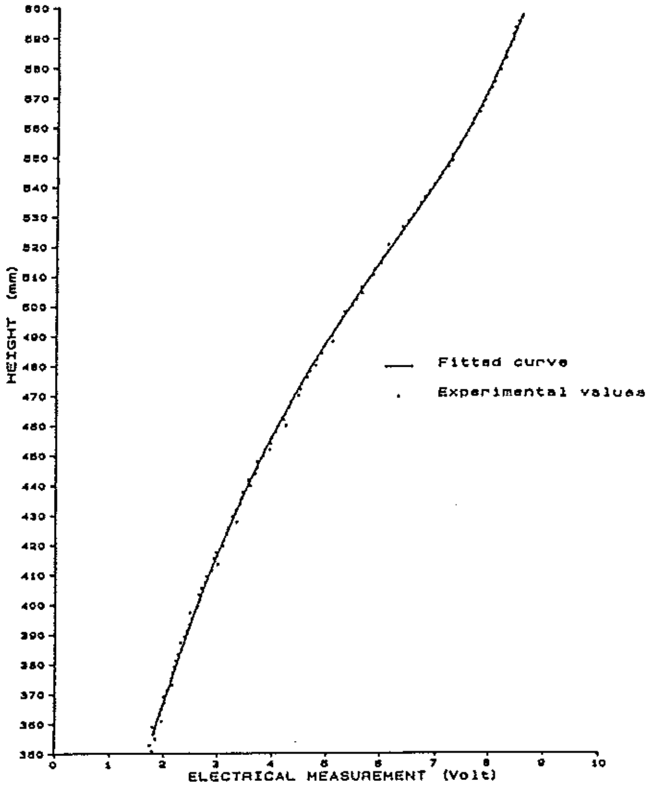
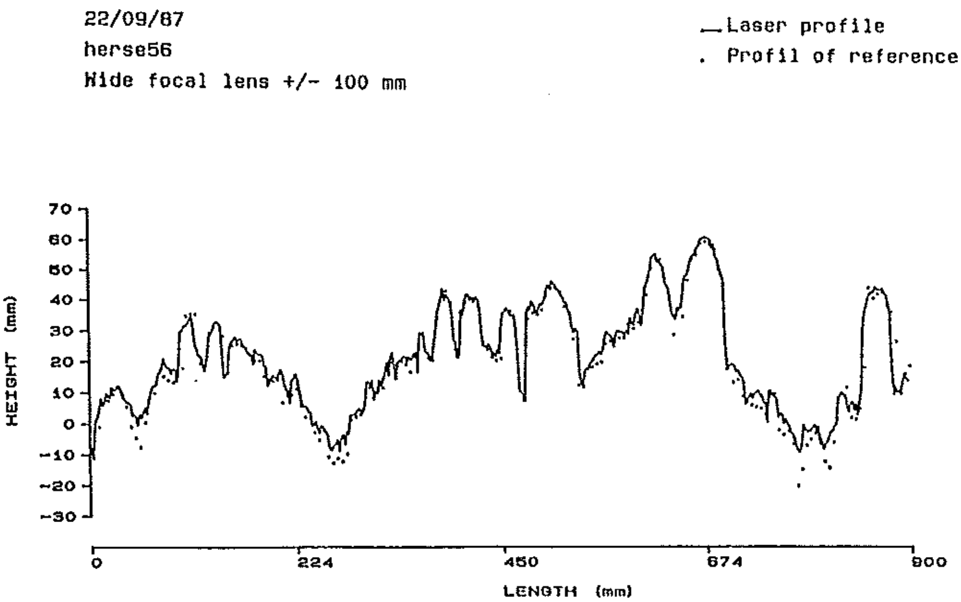


Fig. 3. Calibration curve

Fig. 4. Field test - Comparison with a method of reference



(Volt) and the corresponding range of height (mm). This result is independant of the colour of the sampled profile.

RESULTS

Laboratory tests

Laboratory tests were carried out on standard with particular geometric shapes of different scale in order:

i/ to test the influence of the height distance between the Laser sensor and the sample. Results obtained with the Laser reliefmeter showed that too small distances can give disturbances depending on the choice of the lens and the geometrical characteristics of the shape.Optimal distances have been selected.

ii/ to compute experimental estimations of accuracy of the method. Differences between Laser measurements and their corresponding geometrical shape values were computed. The standard-deviation of these data can be used as a criterion of accuracy. In most cases, the standard-deviation is less than 0.001 m for the small focal lens (± 0.050 m) and less than 0.002 m for the wide focal lens (± 0.100 m).

Field experiment - Comparison with a method of reference

A field test was carried out in order to compare profiles obtained with Laser reliefmeter to those resulting from the use of a geometrical method of reference. This equipment consists of an aluminum bar, bored with 200 holes at a constant increment of 0.005 m. Aluminium pins can slide along holes. A digitized representation of the roughness profile is obtained by getting rods in touch with soil and measuring their height according a horizontal plane of reference (aluminium bar). Fig. 4 shows the obtained result. The profile described by the Laser reliefmeter is in good agreement with the profile of reference. Nevertheless, some small differences appear when comparing measurements obtained in small holes or craks (small height values) . These differences do not affect calculated roughness characteristics specially when the number of experimental data is important.

CONCLUSION

The presented Laser reliefmeter for measuring surface height profile has several advantages. First, this method is non destructive with no contact between the sensor and the soil. Data recording, directly on a microcomputer, is easy and quick in field conditions. There is no need to use a laboratory system for digitizing height profile records. Second, the accuracy and the resolution of the height measurements are small. This method has a great advantage for replicated height profile measurements in field spatial variability studies of roughness parameters.

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UTILIZATION OF WATER BY RYE-SEEDLINGS UNDER CONDITIONS OF RESTRICTED ROOTING

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ABSTRACT

In pot-experiments it was investigated, how the size of non- or only very little rooted aggregates influences the utilization of water by rye-seedlings. The experiments were carried out with a clay soil (52% < 2 µm) and a silt soil (81% < 60 µm) under different climatic conditions.

Aggregate size affects the development of gradients of water tension in the aggregates and hence the supply of water from the aggregates. The effect of aggregate size depends on climatic conditions.

INTRODUCTION

The utilization of water in the soil is influenced by the rooting intensity. The rootability of soil aggregates however is diminished because of increasing soil density as a result of heavy tillage implements. Frequently, roots concentrate on aggregate surfaces and in large pores, i.e. they do not grow through the soil but around the soil (Russel, 1977). Any such tendency for roots will have important implications for the efficiency with which roots can explore the soil total volume for the uptake of water. Water in large aggregates which are not rooted may be available for plants, but not accessible (Heinonen, 1985).

Under these conditions the movement of water to the roots gains more importance. Water will not move to the root unless there is a potential gradient. The potential gradient is a result of a potential difference related to a distance. The potential difference developping in the soil is only a part of an all over potential difference existing between soil, plant, and atmosphere. In this system, the highest potential difference exists between the atmosphere and plants. It will affect the transpirative demand of the plant and hence the potential difference in the soil. Furthermore, the distance between "source and sink" influences the potential gradient. At least, water at a distance from the root if to be available for uptake must move to the plant before irreparable damage occurs. Therefore, the hydraulic conductivity of the soil will affect the movement of water to the root.

Regarding this, the following items were investigated:
a) potential difference against the atmosphere (relative humidity)
b) distance between "source and sink" (size of non-rooted aggregates)
c) hydraulic conductivity (soil texture)

MATERIALS

Pot -experiments with rye-seedlings growing on artificial spherical aggegates of different sizes (2,0 - 4,5 cm) were conducted with low and high relative humidity. The aggregates were produced from homogenous ma= terial from a clay soil (52% < 2µm) and a silt soil (81% < 60µm). Because of a high density the aggregates were not or only little rooted.

Each treatment consisted of one aggregate size and contained the same amount of water resulting from the combination of number and size of aggregates. There was no further water supply. During the experiment, growth of shoots and loss of water from the pots were measured. The ex= periment was terminated at different stages of growth up to the fading of the plants. At these times, root and shoot weight was determined as well as the water content distribution in the aggregates. Water contents were converted to water tensions with a soil water characteristic.

RESULTS

For clayey aggregates the results are plotted in Fig. 1 - 5. Fig. 1 shows that the supply of water from the aggregates is related to the mean gradient of water tension which develops in the aggregates during the time of water depletion. The mean gradient depends on the initial gradient (Fig. 2), which in turn is related to the aggregate size (Fig. 3). These results were obtained under constant climatic conditions.

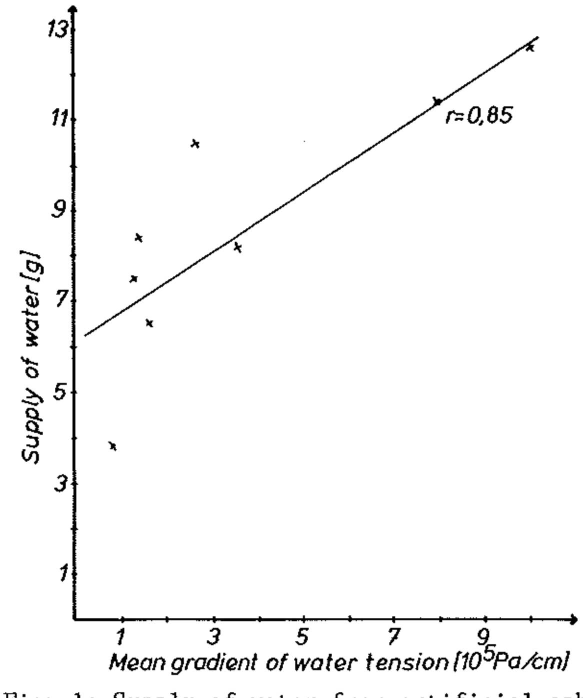

Fig. 1: Supply of water from artificial spherical aggregates (52% < 2µm) in relation to their mean gradient of water tension. Climatic conditions constant.

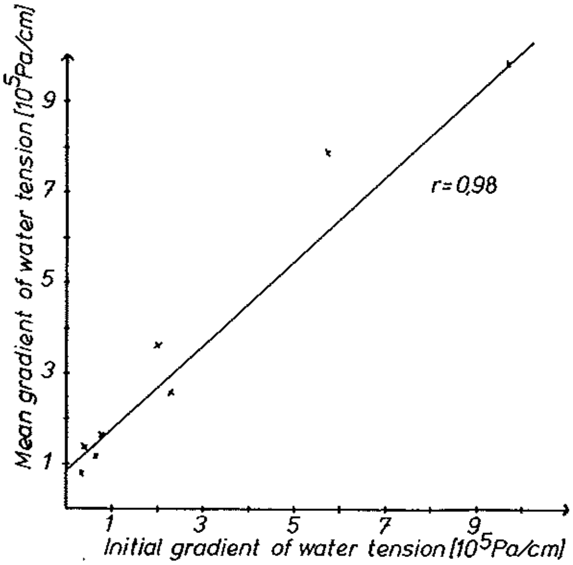

Fig. 2: Mean gradient of water tension in artificial spherical aggregates (52%<2µm) in relation to their initial gradient of water tension. Climatic conditions constant.

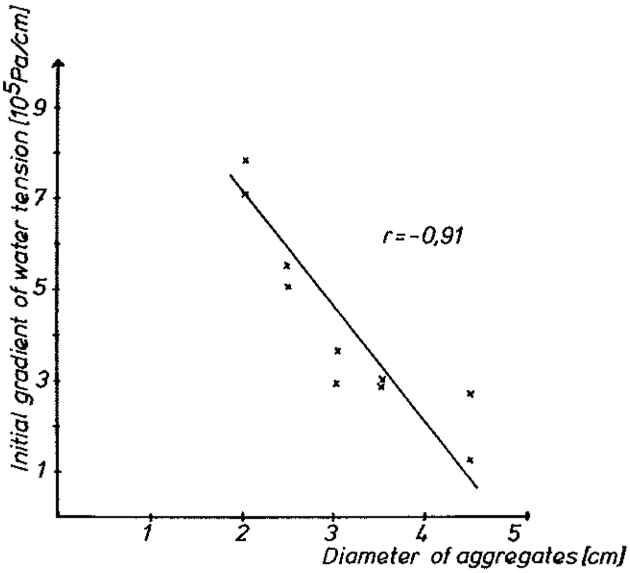

Fig. 3: Initial gradient of water tension in artificial spherical aggre= gates (52%<2µm) in relation to aggregate size. Climatic conditions constant.

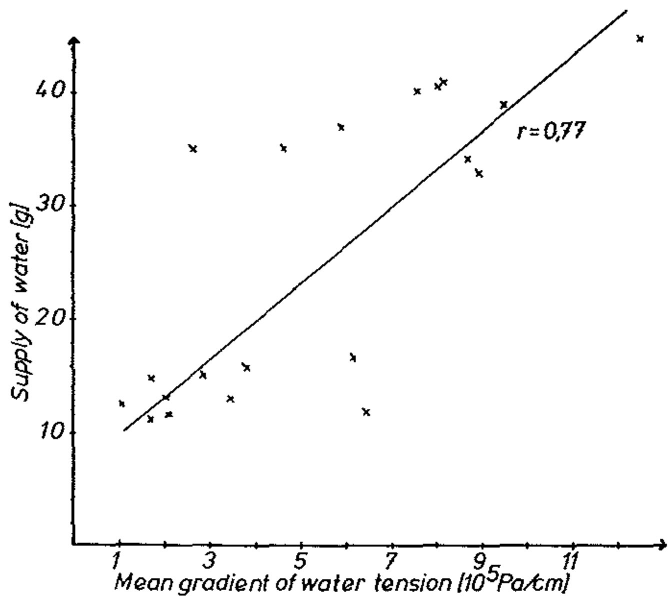

Fig. 4: Supply of water from artificial sperical aggregates (52% < 2µm) in relation to their mean gradient of water tension. Low relative humidity, not constant.

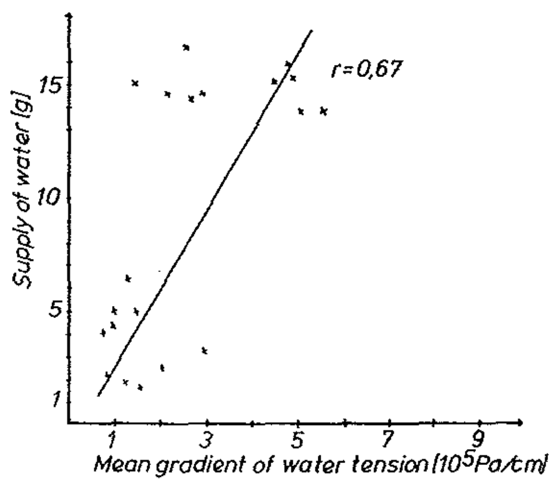

Fig. 5: Supply of water from artificial spherical aggregates (52% < 2µm) in relation to their mean gradient of water tension. High relative humidity, not constant.

Variability in climatic conditions (temperature, light, relative humi= dity) affects these relations. The influence of the aggregate size on the initial gradient is more pronounced with low relative humidity than with high relative humidity. The same applies to the relation between mean gradient and initial gradient of water tension (without figure). Also under varying climatic conditions the mean gradient of water tension affects the supply of water from the aggregates. With low relative hu= midity the relation is more distinct (Fig. 4) than with high relative humidity (Fig. 5). Compared to constant climatic conditions (Fig. 1), in both cases the relation is less distinct.

DISCUSSION

Keeping climatic conditions constant, there is a distinct relation bet= ween the supply of water from aggregates and the mean gradient of water tension in the aggregates. Under these conditions, this relation can be attributed to the aggregate size. A given potential difference against the atmosphere, i.e. a given evapotranspirative demand, results in diffe= rent gradients of water tension depending on the aggregate size.

Obviously, variability in climatic conditions can compensate, support, or counteract the influence of aggregate size, resulting in a less distinct relation between supply of water from the aggregates and gradient of water tension.

CONCLUSIONS

1. Also aggregates which are not or only very little rooted support water for plants.
2. The utilization of water from non-rooted aggregates depends on the size of these aggregates.
3. The effect of aggregate size on the utilization of water is influenced by climatic conditions.
4. Variability of climatic conditions can reduce the effect of aggregate size.

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EFFECT OF CORN AND SOYBEAN CROPPING SYSTEMS ON SOIL STRUCTURAL STABILITY

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ABSTRACT

The structural stability of soils with soybean (Glycine max. [L.] Merr.) cropping is thought to be less than soils with corn (Zea mays L.) cropping. This study was conducted to determine whether differences in structural stability of Webster clay loam (fine-loamy, mixed, mesic Typic Haplaquoll) and Nicollet clay loam (fine-loamy, mixed, mesic Aquic Hapludoll) under corn and soybean cropping systems occur and if these differences are manifested in soil splash and wash losses. Laboratory rainfall simulator/erosion pan and aggregate stability techniques were used to measure structural stability. Differences in aggregate stability by the wet-sieve and raindrop impact methods were not significantly different among cropping systems. Mean weight diameter of sediment from the continuous corn treatment was greater than from continuous soybeans. Differences in splash and wash erosion among cropping systems were not significantly different. We concluded that either differences in structural stability during seedbed preparation period do not exist or differences are apparently overshadowed by antecedent water content effects on structural stability or by disturbance of soil structure during sampling and drying.

INTRODUCTION

Cropping systems greatly influence the structural stability of tillage zone soil. Soybeans as compared to corn, for example, tend to produce a loosened structural condition or tilth that favors improved water infiltration, aeration, and seedling growth (McCracken et al., 1985). Unfortunately, if the soil surface is not protected from raindrop impact with residue cover, this loosened and structurally weak soil condition readily seals or crusts and erodes. Annual soil loss the year following soybeans, therefore, is usually higher than that following corn (Laflen and Moldenhauer, 1979; Alberts et al., 1985). Alberts et al. (1985) found that soil loss was greater the year following soybeans than following corn under conventional tillage in each of five seasonal periods. A significant difference between continuous soybean and corn plots during the period from planting plus 30 days suggests a difference in soil structural stability for a tilled/disked soil condition.

Poor structural conditions contribute to increased erosion, but quantifying the effect of structural stability or aggregate stability on soil loss under different cropping systems has been difficult. For example, Bryan (1974), Luk (1979), and Verhaegen (1984) observed a negative correlation between splash and aggregate stability, whereas McIntyre (1958), Mazurak et al. (1975), Bollinne (1978), and DePloey and Mucher (1981) found splash to be directly proportional to aggregate stability. The certainty that a negative correlation exists between erodibility and aggregate stability (Wischmeier and Mannering, 1969; El-Swaify and Dangler, 1977), however, suggests that infiltration and aggregate transport processes may overshadow the importance of the relationship between aggregate stability and splash.

The objective of this study was to determine whether differences in structural stability of two soils under corn and soybean cropping systems exist and if these differences affect soil splash and wash losses. Laboratory rainfall simulator and aggregate stability techniques were used to measure structural stability.

MATERIALS AND METHODS

Soil materials used in this study were taken from the Ap horizons of a Webster clay loam (fine-loamy, mixed, mesic Typic Haplaquoll) at the Southern Experiment Station, Waseca, MN, and a Nicollet clay loam (fine-loamy, mixed, mesic Aquic Hapludoll) at the Southwest Experiment Station at Lamberton, MN. Both soils are from the same catena with the Nicollet being moderately well-drained and the Webster being poorly drained. Particle size distribution and organic matter percent are given in Table 1. The tillage treatment at both sites was fall moldboard plowed, field cultivated, and disked and was established at least 6 years prior to sampling. The cropping systems were:

1. continuous soybeans (Glycine max (L.) Merr.),
2. continuous corn (Zea mays (L.)),
3. corn following soybeans, and
4. soybeans following corn.

Samples were taken from the no trafficked area just before planting, air-dried in the field, and returned to the laboratory. Large clods were broken by hand until all soil passed through a 20-mm sieve.

Table 1. Particle size distribution and percent organic matter of Webster and Nicollet soils at Waseca and Lamberton, MN.

Soil	Crop†	Sand	Silt	Clay	Organic Carbon	Bulk Density
		%				g/cc
Webster	CC	31	42	27	3.5	1.27
(Waseca)	SS	23	48	29	4.5	1.27
	SC	23	43	34	4.5	1.27
	CS	30	40	30	3.9	1.27
Nicollet	CC	35	40	25	3.3	1.27
(Lamberton)	SS	37	37	26	3.0	1.27
	SC	34	39	27	3.5	1.27
	CS	33	42	25	3.2	1.27

† continuous corn (CC); continuous soybeans (SS); soybeans (1985) - corn (1986) (SC); corn (1985) - soybeans (1986) (SC).

A 75-mm layer of <20 mm air-dried soil was packed over a 125-mm layer of sand in a 320-mm wide by 450-mm long by 200-mm deep erosion pan. A 540-mm high splash shield with a splash collection trough that surrounded both sides and the upslope end of the erosion pan was placed over the pan. The erosion pan was placed at a 9% slope directly under a laboratory simulator (Mutchler and Moldenhauer, 1963) and rainfall was applied for 1 h at an intensity of 55 mm/h. Drop diameter averaged 4.6 ± 0.1 mm and drop height was 4.57 m. A 1-h storm delivered 0.16 J/cm^2 of rainfall energy. Runoff and splash losses were taken at 5-min intervals.

Immediately following each simulator run, the pan was returned to a level position, the soil was saturated, and the matric potential at the soil surface was adjusted to -0.5 kPa and allowed to equilibrate for 3 h. Soil shear strength was then measured using the Swedish fall cone (Bradford et al., 1986). Erosion pan runs for each soil and cropping system combination were replicated twice in a randomized block design.

Sediment size distribution was determined on splash and wash samples collected during a 5 min period ending at 5, 20, 40, and 60 min into the simulated storm. All samples were wet-sieved through a nest of five sieves with openings of 4750, 2000, 1000, 500, and 210 µm and two individual sieves with openings of 125 and 53 µm. Shaking time for the nest of sieves was 10 min. Material less than 53 µm was transferred to a 6000-ml plastic pail and separated into three additional sizes (20, 5, and 2 µm) by standard pipette procedures. The mean weight diameter of sediment for each time period was calculated and reported as the average of two replications (erosion box runs).

Air-dried bulk soil was separated into size fractions of 8-20, 4-8, 2-4, and < 2 mm. Two wetting procedures and two aggregate stability procedures, the wet-sieve method and the waterdrop impact method, were used on selected aggregate sizes and cropping treatments. The wetting procedure included either air-dried aggregates or aggregates slowly wetted for 36 h on a tension table maintained at a -0.5 kPa water potential. The wet-sieve method was similar to the sediment size distribution procedure, except with a variable shaking time of 3, 30, and 60 min. The waterdrop impact method was a modification of the Young (1984) method. Fifty grams of either air-dried or prewetted aggregates were placed on a 200-mm diameter 500 µm sieve with a 600-mm high splash shield. The sieve was attached above a 6000-ml plastic pail and placed under a laboratory rainfall simulator at a rainfall intensity of 67 mm/h, for durations of either 10, 30, or 60 min. The soil on the sieve and in the pail was transferred to the wet-sieving apparatus and the above wet-sieving procedures were followed, except with a constant shaking time of 30 min. The particle size distribution of duplicate samples was plotted and the mean weight diameter calculated.

RESULTS

A summary of the results of the erosion pan studies is given in Table 2.

Table 2. Runoff, soil loss, and surface shear strength at selected sampling periods of a 60-min simulated rainstorm.

		Soil loss†			Splash			Wash	Runoff		Strength
Soil	Crop	E_{max}	E_{60}	E_T	S_{max}	S_{60}	S_T	W_T	R_{60}	R_T	τ_{60}
		g							--mm/h--		kPa
Nicollet	CC	71	45	584	58	35	470	113	29	19	20
	SS	88	53	753	71	38	583	169	40	28	17
	CS	81	43	627	65	28	487	140	33	24	18
	SC	78	47	641	61	33	492	148	34	22	19
Webster	CC	88	51	697	71	37	554	143	33	21	18
	SS	83	45	643	71	33	532	110	31	20	18
	CS	82	51	659	70	39	547	112	27	17	17
	SC	87	52	669	73	40	551	118	30	18	20
	LSD(0.05)	7.3	8.8	90.0	6.3	6.3	68.2	26.6	3.6	3.0	

† E_{max} is the maximum soil loss rate and S_{max} is the maximum splash rate during a 5-min sampling period. E_{60}, S_{60}, and R_{60} are soil loss, splash, and runoff during the 55- to 60-min sampling period. E_T, S_T, W_T, and R_T are the total soil loss, splash, wash, and runoff, respectively, occurring during the 60-min rainstorm. τ_{60} is the shear strength measured after 60 min of rainfall.

Analysis of variance of the data for each erosion parameter indicated that the soil, crop, and soil x crop treatment effects for soil loss parameters were not significant at the 0.05 probability level ($p < 0.05$), except for a soil effect for the maximum 5-min period soil splash (S_{max}). Significant (p

< 0.05) soil effects were found for R_{60} (runoff for the 55 to 60 min period) but not for R_T (total runoff). There were no differences in fall-cone strength among soils or cropping treatments. Least significant difference (LSD) values at $p < 0.05$ are given in Table 2; however, comparison of means are not valid unless the F test of treatments is significant.

Mean weight diameters (MWD) calculated from the sediment size distribution for wash and splash from the erosion pan studies are given in Table 3. Analysis of variance of the data indicated significant ($p < 0.05$) soil, cropping, erosion source, and sampling time main effects and a significant erosion x time interaction. The other 2-way and 3-way interactions were not significant. Since the soybean following corn and corn following soybean treatments were not significantly different and did not differ from the continuous corn treatment, the data for these two cropping treatments are excluded from Table 3.

The weight MWD for Webster sediment averaged over other treatments was greater than the MWD for Nicollet sediment, and the MWD for continuous corn was greater than for continuous soybeans averaged across other treatments. With time, wash and splash MWD increased up to 20 min and then decreased thereafter, with the rate of decrease of wash much greater than splash. There were no consistent trends in cropping effects across soils and sediment source.

Table 3. Mean weight diameter (mm) of sediment collected in erosion pan studies.

Soil	Cropping system	Sediment source	Sampling time (min) 5	20	40	60
Webster	CC	splash	0.36	0.47	0.38	0.32
		wash	0.46	0.48	0.23	0.28
	SS	splash	0.32	0.47	0.35	0.29
		wash	0.41	0.43	0.19	0.16
Nicollet	CC	splash	0.37	0.39	0.36	0.32
		wash	0.33	0.43	0.27	0.18
	SS	splash	0.30	0.37	0.32	0.33
		wash	0.40	0.32	0.28	0.22

Aggregate stability results for the Nicollet soil for continuous corn and continuous soybeans are given in Table 4. There were significant differences among aggregate sizes and between prewetting treatments and aggregate stability methods; however, there were no differences among cropping systems. Aggregates prewetted at 5 cm tension were stronger than the initially air-dried aggregates. The addition of energy into the aggregate stability method, whether by increased shaking time in the sieving method or rainfall duration in the raindrop impact method, reduced MWD. Since raindrop impact energy greatly exceeds that imparted to the soil by the sieving method, the MWD's for the raindrop impact method are lower.

DISCUSSION

The erosion pan studies do not indicate differences in splash or wash rates between corn and soybean cropped soils. The companion sediment size and aggregate stability results do, however, allow some speculation on possible reasons for not detecting differences between cropping systems. First, there is no absolute proof that differences in soil loss between the two soils occur at the seed bed preparation period. Mannering and Johnson (1969) found no significant differences in soil loss from soybean and corn in the first 8 weeks of the growing season, and Laflen and Colvin (1981) were unable to detect differences in soybean and corn on soil loss using simulated rainfall, if residue cover values were similar. Second, differences in cropping treatments that actually exist in the field may be obscured by alterations in soil structural stability that occurred during the soil sampling, transport, and drying procedures. The drying process changes the soil fabric, with the magnitude of the change largely dependent on soil texture and interparticle bonding. Third, if we assume that soil erodibility is inversely related to aggregate stability, and aggregate stability is a function of antecedent moisture content (Table 4), cropping treatment differences in splash or wash erosion in laboratory erosion pan studies will be found only if the moisture content of the pan soil is maintained at its in situ value. Drying soil from each cropping treatment to an air-dry condition may be responsible for the lack of detectable differences in this study.

Table 4. Mean weight diameter (mm) from aggregate stability analyses.

Soil	Aggregate Size (mm)	Prewetting treatment	Cropping system	Sieve Method Shaking time (min) 3	30	60	Raindrop Impact Method Rainfall duration (min) 10	30	60
Nicollet	2-4	dry	CC	1.19	0.62	0.65			
			SS	0.80	0.55	0.60			
		wet	CC	1.63	1.39	1.36			
			SS	1.46	1.12	1.30			
	4-8	dry	CC	1.40	0.87	0.87			
			SS	1.21	0.71	0.70			
		wet	CC	4.43	3.38	4.79			
			SS	3.31	3.55	3.00			
	8-20	dry	CC	2.03	1.19	1.05	0.49	0.39	0.32
			SS	1.73	0.71	0.68	0.48	0.39	0.31
		wet	CC	6.00	5.83	5.78	4.33	2.72	2.30
			SS	6.19	5.91	5.66	4.56	3.04	1.67

CONCLUSIONS

Based on a laboratory study of splash and wash erosion behavior and a series of aggregate size and stability tests, the following conclusions are drawn:

1. Differences in splash and wash erosion among four cropping treatments (continuous corn, continuous soybeans, corn following soybeans, and soybeans following corn) in laboratory simulated rainfall/erosion pan studies were not significantly different.

2. Mean weight diameter of sediment from the continuous corn treatment was greater than from continuous soybeans. The mean weight diameter of the wash was significantly less than that of the splash.

3. Differences in aggregate stability by the wet-sieve and raindrop impact methods among cropping systems were not significantly different.

4. If differences in soil loss between corn and soybean cropping systems actually exist, researchers must re-examine the use of laboratory erosion pan techniques and soil sampling, especially drying and prewetting, procedures.

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THE EFFECT OF BULK DENSITY ON ROOT GROWTH

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ABSTRACT

Roots of three different species were subjected to two confining pressures in a modified triaxial cell. Bulk density changes due to root growth were observed using a radiography technique. It was found that roots tend to elongate through soil by cylindrical compression and that this zone did not appear to extend ahead of the root tip. Roots elongating through high strength soil were observed to have narrow tips and to be expanded behind the tip. It is postulated that this may be an important mechanism whereby roots penetrate high strength soils.

INTRODUCTION

The mechanical behaviour of soil can impose limitations to root growth, which may in turn reduce yield. The use of heavier machinery and reduced-tillage techniques can lead to increased compaction which may restrict root growth. The degree of compaction largely determines the physical and chemical soil properties that control crop response. Compaction establishes the air, water and temperature relationships which influence germination, emergence and root growth.

When a soil is compacted the bulk density increases and this is accompanied by a reduction of mean pore diameter, which is often associated with greater resistance to root penetration. An increase in bulk density is also associated with a reduction in air filled porosity. Water and nutrient availability may also change. A dense soil is usually poorly aerated and may often contain excess water. Each of these factors may reduce the growth of roots and shoots, but the relative importance of each varies depending on crop species, environmental conditions and cultural practice.

The effect of compaction on root growth has been extensively reviewed in the literature (Greacen et al 1969; Barnes et al 1971; Taylor et al 1972; Scott-Russel 1977). Recently, model experiments have been conducted to examine the forces that roots exert in penetrating soil and whether or not roots will penetrate soil aggregates and cracks (Misra et al 1986a, b; Dexter 1986a, b; Richards and Greacen 1986).

An understanding of the mechanism whereby roots grow through compacted soil would be useful in the analysis of problems concerned with, 1) the influence of soil compaction on root growth, and 2) cultivation required to establish a satisfactory root environment. Greacen et al (1968) proposed that roots grew through soil by radially deforming the soil through cylindrical expansion. Abdalla et al (1969) observed that when a root grows through high strength soil, axial elongation ceased and the meristematic region expanded radially. They postulated that this radial thickening weakened the soil ahead of the root tip thus enabling axial extension to continue. This has tended to be confirmed by observations of Richards and Greacen (1986) studying the cylindrical expansion of a simulated 'root' which produced a zone of radial tensile strain ahead of the 'root'. The reduction in stress in front of the root explains the observations of Abdalla et al (1969) and the difference in behaviour between penetrometers and roots.

This study was undertaken to investigate the soil weakening phenomenon which had been postulated by examining the growth of roots of three species through two soils known to develop high strength. Since soil strength is positively correlated with bulk density, the effect was to be examined through reduction in bulk density in front of radially expanding roots. Soil density changes were determined by using an X-ray radiography technique on impregnated thin sections.

MATERIALS AND METHODS

Roots of wheat, maize and pea were grown into prepared soil samples subject to pressures of 0.1 and 0.2 MPa in a modified triaxial cell (Barley 1963). A sandy loam and a fine sand soil were used in the study. Samples were collected from the 0-10 cm layer from Waite Agricultural Research Institute and at Meadows, South Australia.

A set of standard bulk density (1.1-1.8 Mg m^{-3} in 0.1 increments) samples were prepared to enable changes due to root growth to be assessed. All samples were treated similarly. Samples were impregnated under vacuum with epoxy resin (Araldite LC191 in a 1:5 mix) according to the technique of Greacen et al (1967). For the higher density samples the technique was modified to include heating the epoxy for 5 minutes and applying a positive pressure to force the epoxy into the sample. Sample size was 38 mm diam. by 40 mm high. The initial bulk density of samples was 1.25 Mg m^{-3}.

Pregerminated seeds of each species were used, with the radicals being placed into pilot holes in the sample. Seeds were prevented from desiccating by placing cotton wool and sand over them. After 12 hrs growth, external pressure was applied for 12 hrs. Volume change of the sample was noted. The experiments were conducted at 25°C in a constant temperature room. Samples were dried at 60°C for 48 hr and then impregnated and sectioned into 2 mm sections using a diamond saw. Sections were exposed to X-rays using a home-made camera on a Mueller Mikro 91 machine. The source to specimen distance was 38 cm with a take-off angle of 6 degrees. An exposure time of 10 min at 15 kV and 10 mA was used.

A constant depth (10 mm) penetrometer was used to determine soil strength of the cores under the same conditions as for the root growth experiments.

Assessment of bulk density change from the root surface out into the bulk of the sample was by subjective comparison with the prepared set of standard bulk densities.

Both root diameter and length were measured on the X-radiograph; the diameter 2 mm behind the tip and the length from the edge of the radiograph to the root tip.

RESULTS

The sandy loam soil compacted to a higher bulk density than the fine sand soil at both applied pressures (Fig. 1a). This reflects the difference in particle size distribution of both soils and water content, with the water content at -10 kPa suction being 22.2 and 17.6 percent for the sandy loam and fine sand, respectively. For both soils, however, bulk density increased with increasing applied pressure.

This difference between soils is also evident in the soil strength measurements, except for the 0.2 MPa applied pressure where the fine sand is stronger than the sandy loam (Fig. 1b). Again this may reflect differences in water content, but more likely the degree of inter-locking between the sand grains increased at the higher applied pressure in the fine sand. For both soils, soil strength has increased with increasing applied pressure.

Soil bulk density decreased rapidly with distance from the edge of the root (Fig. 2 a,b,c,d) for both soil types. A compacted zone of approximately two millimetres cccurs around the roots exposed to both applied pressures. The main difference being higher bulk densities at the higher pressure. Maize roots appear to compact the soil to higher densities than either the wheat or pea roots. It must be remembered that these assessments are purely subjective comparisons and not actual measurements. Notwithstanding that, trends are quite obvious.

Root diameter (Fig. 3a, b) and length (Fig. 4a, b) tended to increase and decrease, respectively for all species at both applied pressures in both soils. There were exceptions to this with wheat and maize roots increasing in diameter in the fine sand with an increase in pressure (Fig. 3b) and maize roots increasing in length with an increase in pressure in both soils (Fig. 4a, b). This may be due to biological variation in the plants tested or differences in packing density, although from the X-radiographs it appeared uniform.

DISCUSSION

The differences in root growth observed in the two soils examined are probably due to differences in soil texture and water content. The ability of different roots to penetrate high strength soil are probably related to biological variation. Specific differences may be detected if larger numbers of replicates are tested.

There are inherent problems in the technique used, the main one being, if in fact, a root tip has been included in the section. A root cut diagonally would have the appearance of being a root tip. One way to overcome this would be to stain the root tip with a non-translocating dye. To measure changes in bulk density more accurately a fine line microphotometer could be used.

As shown in Fig. 2 bulk density decreased from the root surface out into the bulk of the sample. Similar observations were made by Greacen et al (1968). Less change appears in the find sand, presumably due to a higher initial porosity, thus any compression due to root growth would be taken up by a decrease in large pores with very little change in bulk density.

It appears that fibrous root systems may have an advantage in penetrating soil since wheat and maize roots are longer than the pea roots in both soils under a 0.2 MPa confining pressure. This may be a function of root diameter which interacts with the porosity of the soil.

It has been observed that when axial root growth is restricted roots expand radially (Barley 1968; Taylor et al 1972). However, it is not known whether the applied pressure stopped axial growth. Roots have increased in diameter in response to the applied pressure (Fig. 3), but axial growth has probably continued at a reduced rate. The increase in diameter has caused compression along the sides of the roots and this zone does not extend ahead of the root tip. It was also observed that density did not visibly decrease ahead of the root. It appears that the roots have penetrated the soil according to the model of cylindrical compression as proposed by Greacen et al (1968) and more recently confirmed theoretically by Richards and Greacen (1986). According to the model the zone of compression should be about six times the radius of the root. From observations of the X-radiographs it appears that the average radius of compression is four to five times that of the root, which is further evidence that root penetration of soil follows the proposed model. The zone of influence is affected by the position of the root in the section, so the agreement is within experimental error.

It was noted that the roots were narrower at the tip and wider behind the tip in the samples under 0.2 MPa than those under 0.1 MPa applied pressure. This tends to agree with the observations of Barley (1968) and Abdalla et al (1969). Most previous experiments have used pure graded sands or glass beads as growth media and expanding rubber cylinders to simulate roots, whereas in this study actual roots were observed <u>in situ</u>.

CONCLUSIONS

1) The technique employed enables roots to be observed <u>in situ</u> and qualitative assessment of density changes due to root growth.

2) It appears that root growth follows the cylindrical compression model of Greacen et al (1968).

3) Within limits of experimental error the compression zone does not extend ahead of the root.

4) Roots experiencing large external pressures tend to have narrow tips with the proximal area behind the tip being wider, which agrees with observations of Abdalla et al (1969).

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Figure 3. Effect of Applied Pressure on Root Diameter.

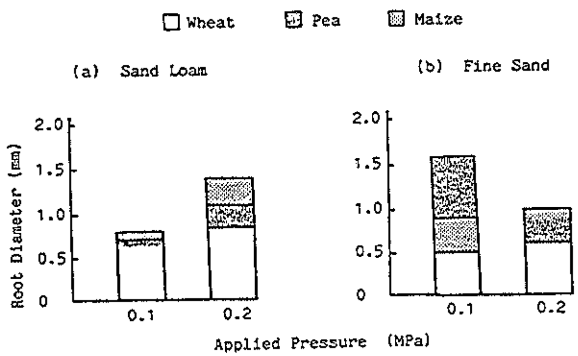


Figure 4. Effect of Applied Pressure on Root Length.

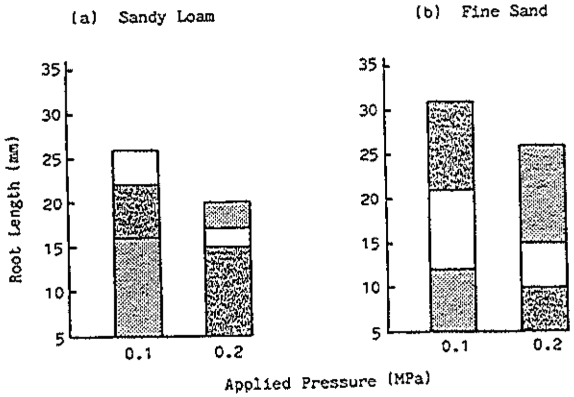


Figure 1. Effect of Applied Pressure on Bulk Density and Soil Strength.

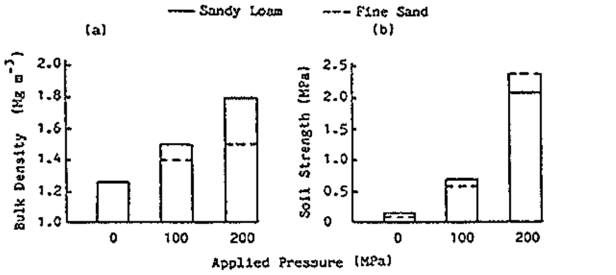
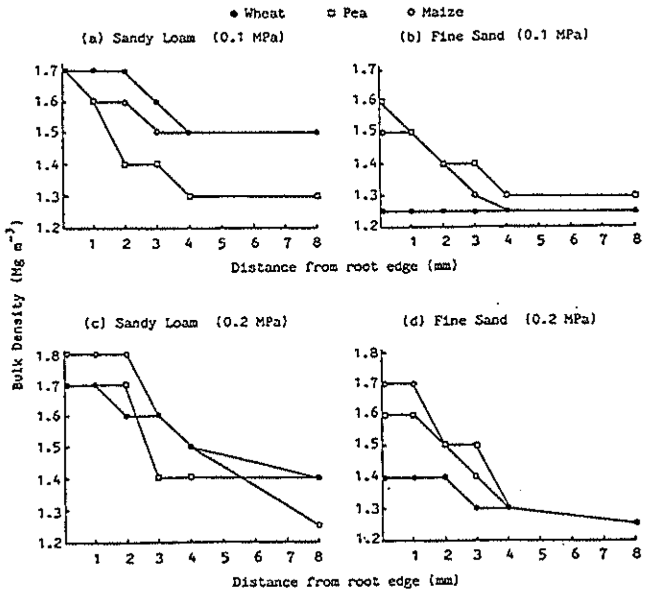


Figure 2. Change in Bulk Density due to Root Growth.



INFLUENCE OF SOME ORGANIC AND INORGANIC SOIL CONDITIONERS UPON THE YIELD OF WINTER WHEAT, MAIZE AND SUGAR BEET, AND SOME MICROBIOLOGICAL PROPERTIES OF HEAVY SOIL

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ABSTRACT

The hazards of intensive anthropogenic soil compation, with frequently inadequate tillage and crop production systems, as well as insufficient "turnover" of organic matter in the soil, often result in increased deterioration of soil structure. Therefore, field experiments were carried out for several years with two organic and two inorganic soil conditioners, i.e. bituminous emulsion, polyacrylamide, glotal and tripher, on semigley and hypogley, with three crops in rotation (winter wheat, maize and sugar beet). As regards the crop yield and the microbiological state of soil complex, the effects of the conditioners were generally favourable, depending on the kind and rates of conditioners applied, soil type and weather conditions.

INTRODUCTION

The hazards of increasing anthropogenic compaction of soil, and thereby increased deterioration of soil structure on agricultural areas under intensive cultivation, as well as insufficient "turnover" of organic matter in the soil, were the starting point in searching for new solutions that could eliminate or alleviate these defects. Modern systems of soil tillage and field crop production, especially in the socialized sectors of Yugoslav agriculture, are often not adjusted to the site characteristics, that is prevailling ecological conditions. Hence the need for solving the increasing problems of the soil fertility and finding alternative ways of its increase. One of the possibilities is the application of soil conditioners. Investigations of the conditioners carried out in different parts of the world were more or less successful, depending on the "fertilizing" effect of these agents, "mechanism" of their activity in the soil, as well as the conditions under which they were applied. A detailed report of these investigations was given earlier (Butorac et al., 1982, Redžepović, 1982). Investigations of soil structure stabilizing agents are intensively carried out in Belgium (De Boodt and De Bischop, 1974, etc.), in Italy (Piccolo, 1974, Landi, 1978 etc.), the USSR (Epshtein and Revut, 1974) and German Demokratic Republic (Kullman, 1982). Conditioners are being futher studed from different aspects (Sen and Bhadoria, 1987, Shaviv et el., 1987).

In our earlier investigations (Butorac et el., 1982), conditioners showed a positive effect on the yield of spring oats, winter wheat and soybean. They had variable effect on the physical and chemical soil properties and some major microorganisms.

MATERIALS AND METHODS

Investigations of the efficiency of soil conditioners began in the spring of 1979 on semigley and hypogley soils in the lowland Pannonian part of Croatia. Water and air holding capacity of semigley is 37.5 and 6.2%, respectively, while that of hypogley 42.8 and 8.1%, respectively; porosity of semigley amounts to 43.4% and that of hypogley 50.7%; dry bulk density is 1.47 for semigley and 1.36 for hypogley; clay content is 29.1 and 33.2%, respectively, while the stability factor of macrostructural aggregates is

43 in semigley and 41 in hypogley. Soil pH in semigley ranges from 5.0 to 5.8, and in hypogley from 5.0 to 5.7. In booth soil types there is average availability of phosphours and potassium. Saturation with bases ranges between 67 and 83 in semigley, and 79 and 84% in hypogley.

The trials involved four conditioners, each in two rates, including control: bituminous emulsion, polyacrylamide, glotal and tripher. With respect to the properties and nature of the conditioners, as well as the desired results, glotal and tripher were applied by broadcasting before the basic tillage whereas bituminous emulsion and polyacrylamide, with glyoxal added for dilution, each successive year after crop planting. Crops were alternated in the trials according to a set scheme within a three field crop rotation. The trials were set up according to the randomized block method in four replications. The experimental plot size was 15 m^2. The trials were of stationary character, which enabled us to follow up the changes in the physical, chemical and biological soil complex. Besides the yield, the paper presents only a few changes in the biological soil complex effected by the applied conditioners. Lower and higher doses of glotal and tripher were 6 and 12 t/ha, respectively. Lower and higher doses of bituminous emulsion were 0.25 and 0.5 t/ha, respectively, while those of polyacrylamide 0.2 and 0.3 t/ha, respectively.

Physical, chemical and microbiological analyses of the soil were carried out using the standard laboratory methods. The achieved yields of winter wheat and maize grain and sugar beet roots were variationally statistically processed by the analysis of variance.

RESULTS AND DISCUSSION

Effect of soil conditioners on the yield of wheat, maize and sugar beet

Results obtained in the investigations are presented according to soil types and crops. In the case of winter wheat treatment of semigley with soil conditioners had only partly a significant effect on grain yield (Table I). However, there are certain differences between years. The mean 4-year grain yields show that all the conditioner treated soils rendered, though not significantly, better results than the control, which points to a positive effect of theconditioners upon the yield. Glotal was the most efficient conditioner used.

On hypogley, there were significant differences between treatments in grain yields of winter wheat in two of the three investigation years (Table I). Hypogley is an expressly heavy soil type. In the second year, wheat was replaced by spring barley in the trial. Due to exceptionally unfavourable weather conditions, its yield was low but the effect of conditioners was present. The mean 3-year results obtained with winter wheat on hypogley indicate that the effect of conditioners was minimal, or non-existent, depending on the kind and rate of conditioner. Though with minimal advantage, the first place is occupied by glotal, while some treatments are significantly worse even than the control. Grain yields of winter wheat showed great oscillations per years, so also in this respect the trial is significant.

On semigley, there were significant differences in the yield of maize grain in three of the five investigation years (Table II). Not analyzing the efficiency of individual conditioners in discrete years, which was incidentally quite consistent, we are pointing out that semigley is a soil type which is by itself a suitable substratum for maize growing, which is confirmed by the mean 5-year results. Also in the case of maize, glotal showed the best efficiency on semigley, which could indicate the advantage of inorganic over organic conditioners.

TABLE I
Grain yield of wheat according to treatments, soil types and years, t/ha

Treatment	Rate	1980	1981	1982	1983	Average
		Soil type: semigley				
Bituminous emulsion	Lower	4.59	2.14	3.93	6.59	4.32
Bituminous emulsion	Higher	3.99	2:90*	4.26	7.59	4.69*
Polyacrylamide	Lower	4.08	2.36	4.53	6.59	4.44
Polyacrylamide	Higher	4.09	2.16	4.59	6.79	4.42
Glotal	Lower	3.77	3.02*	4.59	7.66	4.76**
Glotal	Higher	4.36	3.26**	4.73	7.32	4.92**
Tripher	Lower	4.44	2.67	4.06	6.66	4.46
Tripher	Higher	3.59	3.44**	4.26	6.92	4.56
Control		4.08	1.85	3.93	7.06	4.24
		Soil type: hypogley				
Bituminous emulsion	Lower	2.62	1.86+	4.26**	5.26	4.06
Bituminous emulsion	Higher	2.63	1.81	4.26**	5.66	4.20
Polyacrylamide	Lower	2.82	1.57	4.33**	5.66	4.27
Polyacrylamide	Higher	3.02	1.64	3.92	5.19	4.04
Glotal	Lower	3.36	1.60	3.92	5.73	4.36
Glotal	Higher	3.24	1.93	3.92	5.79	4.34
Tripher	Lower	2.91	1.83	3.99	4.92	3.96
Tripher	Higher	3.26	1.57	3.79	6.19**	4.08
Control		3.06	1.67	3.79	5.66	4.19

Significantly different with respect to the control: *P=0.05, **P=0.01
+ Spring barley instead of winter wheat on hypogley

TABLE II
Grain yield of maize according to treatments, soil types and years, t/ha

Treatment	Rate	1979	1980	1981	1982	1983	Average
		Soil type: semigley					
Bituminous emulsion	Lower	11.98	10.12	11.25	15.45	8.19	11.43
Bituminous emulsion	Higher	12.45	11.97	11.45	15.85	8.39	12.03
Polycarylamide	Lower	12.92	12.02	11.32	15.65	7.99	11.99
Polyacrylamide	Higher	12.65	11.56	9.86	15.91	7.92	11.59
Glotal	Lower	12.45	12.75**	11.79	16.38	8.39	12.35**
Glotal	Higher	13.18	12.65	11.06	16.05	7.92	12.18*
Tripher	Lower	12.98*	12.06	10.66	16.38	7.92	12.00
Tripher	Higher	12.92	12.33**	11.19	15.78	7.66	11.98
Control		12.65	10.68	10.78	15.85	8.19	11.65
		Soil type: hypogley					
Bituminous emulsion	Lower	12.32	12.32	9.32	10.58	9.06*	10.73
Bituminous emulsion	Higher	12.05	11.26	9.12	10.19	8.72	10.28
Polyacrylamide	Lower	11.92	12.05	9.52	10.38	8.72	10.54
Polyacrylamide	Higher	11.52	10.92	8.72	9.72	8.52	9.88
Glotal	Lower	12.52	12.65	9.25	9.92	9.06*	10.70
Glotal	Higher	12.12	11.72	9.19	10.25	8.66	10.38
Tripher	Lower	12.45	12.58	8.92	11.52**	8.92	10.86*
Tripher	Higher	12.99	10.78	8.12	11.05*	9.19*	10.44
Control		11.52	11.99	9.39	9.65	8.45	10.22

Significantly different with respect to the control: *P=0.05, **P=0.01

The analysis of variance performed for the yield of maize grain on hypogley points to the very low degree to significance between trial treatments (Table II). Still, there are certain differences both between trial treatments in the same year and between individual years, the efficiency of conditioners showing a slight improvement in the last two years. However, observing the mean yields of maize grain on hypogley in the 5-year period one gets the impression that the effect of conditioners is not fully defined despite the general trend of their positive influence. Only the lower tripher rate is significantly lower than the control. Though the differences in yields per years, irrespective of the treatment, are relatively strongly expressed, generally high yields were obtained in all the years, which relegates the use of conditioners to a secondary role. Oscillations of yields, despite identical measures in all treatments, is undoubtedly due to variable meteorological conditions.

The yield of sugar beet roots on semigley varied considerably per years (Table III). However, there are differences between treatments. Considering only the 6-year average yield per trial treatments, it can be concluded that all conditioner treatments, except for the lower rate of bituminous emulsion, were better than the control. Significantly higher yields than that of the control were achieved with higher rates of tripher and glotal. Therefore, it should be emphasized that glotal proved to be the leading conditioner also in the case of the yield of sugar beet roots on semigley. However, the effects of other conditioners cannot be disregarded and, on the whole, their application seems to be justified.

TABLE III
Yield of sugar beet root according to treatments, soil types and year, t/ha

Treatment	Rate	1979	1980	1981	1982	1983	1984	Average
				Soil type: semigley				
Bituminous emulsion	Lower	47.55	47.55	23.24	55.47	72.09	70.18	52.71
Bituminous emulsion	Higher	50.81	47.75	48.55	53.48	77.09	72.01	58.25
Polyacrylamide	Lower	50.21	48.35	44.95	50.55	78.92*	68.10	56.86
Polyacrylamide	Higher	52.48	47.82	37.63	53.61	78.26*	71.34	56.86
Glotal	Lower	49.88	48.62	51.55	53.14	77.26	71.43	58.66
Glotal	Higher	53.67	51.62	60.41	55.61	82.92	78.42	63.94*
Tripher	Lower	50.54	46.35	39.23	50.22	74.86	72.48	55.62
Tripher	Higher	58.00	52.48*	53.75	52.01	76.47	80.25	62.17*
Control		48.35	40.09	36.89	58.60	71.38	66.35	53.61
				Soil type: hypogley				
Bituminous emulsion	Lower			59.54	25.24	35.88		40.23
Bituminous emulsion	Higher			57.61	23.17	35.01		38.61
Polyacrylamide	Lower			49.15	23.84	36.76		36.60
Polyacrylamide	Higher			47.82	23.37	37.36		36.21
Glotal	Lower			53.87	25.71	35.15		38.26
Glotal	Higher			60.07	22.37	36.63		39.71
Tripher	Lower			61.54	25.24	36.76		41.20
Tripher	Higher			59.07	24.17	32.42		38.57
Control				53.41	24.64	31.30		36.45

Signiticantly different with respect to the control: *P=0.05, **P=0.01

The analysis of variance carried out for the yield of sugar beet roots on hypogley shows that there were no significant differences between treatments (Table III). However, in a sense, there are certain differences and, according to the mean 3-year results, all the treatments, with the exception of the higher rate of polyacrylamide, were better than the control.

But oscillations of yields per year are evident, like in the cases of winter wheat and maize, which points to unfavourable effective fertility of hypogley, which seems to be partly due to variable hydrometerological characteristics of the climate.

Not giving a detailed analysis of the obtained results, because of limited space, it should be only pointed out that the efficiency of the investigated conditioners varied in accordance with their properties, i.e. the "mechanism" of their effect, characteristics of the soil type, specific response of the crop, and the constellation of some important meteorological elements, primarily the hydrothermic characteristics of the climate, with a possibility of a certain degree of interaction between the mentioned factors.

Effect of conditioners on some microbiological properties of the soil

The results of 5-year investigations of the effect of higher rates of organic (bituminous emulsion and polyacrylamide) and inorganic (glotal and tripher) conditioners shows that there were no significant differences in their effect on aerobic asymbiotic nitrogen-fixing bacteria in semigley and hypogley under winter wheat, maize and sugar beet (Fig. 1.a)

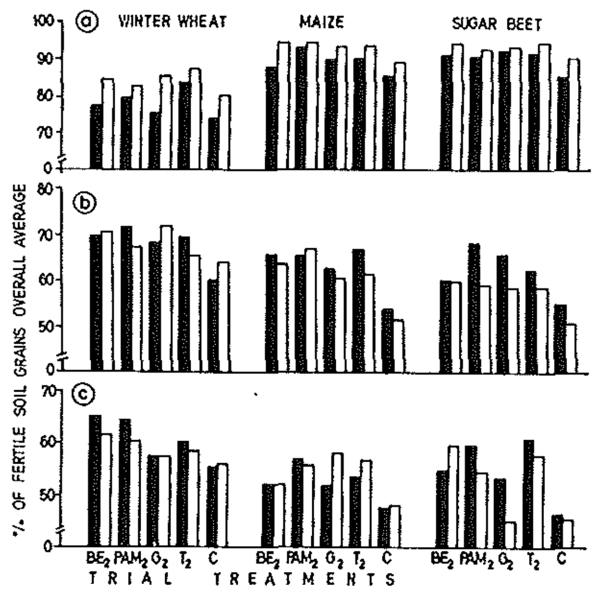

Fig.1 RELATIVE GROWTH OF AEROBIC ASYMBIOTIC NITROGEN-FIXING BACTERIA ⓐ, AMMONIUM OXIDIZING BACTERIA ⓑ AND NITRITE OXIDIZING BACTERIA ⓒ.
(BE_2 = bituminous emulsion, PAM_2 = polyacrylamide, G_2 = glotal, T_2 = tripher, C = check).
SOIL TYPE: ■ = semigley □ = hypogley

It is characteristic that in the whole investigation period, regardless of the trial treatment, almost the only species of aerobic asymbiotic nitrogen-fixing bacteria that occurred in semigley was Azotobacter chroococcum However, in hypogley, representatives of the nitrogenous species Azomonas macrocytogenes also appeared.

In all the trial treatment soil conditioners brought about an increase in the content of nitrite and nitrate bacteria in comparison with the control on semigley and hypogley, irrespective of the test crop being wheat, maize or sugar beet (Fig. 1.b and 1.c).

CONCLUSIONS

1 The applied organic and inorganic soil conditioners had a positive effect on the yield of winter wheat and maize grain, as well sugar beet roots, on semigley, though this soil type is by itself favourable for growing deeply rooted crops. Their efficiency on hypogley, in relation to the yield of the same crops, was variable, depending on the crop, the rate and type of soil conditioner, considering also the adverse effective fertility of hypogley.

2 Soil conditioners had no significant effect on the content of aerobic asymbiotic nitrogen-fixing bacteria and nitrifiers on semigley and hypogley under winter wheat, maize and sugar beet, though their positive effect was felt in comparison with the control.

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SOIL STRUCTURE AND RELATED PROPERTIES OF A SILT LOAM CROPPED FOR NINE CONSECUTIVE YEARS WITH SILAGE CORN UNDER REDUCED AND CONVENTIONAL TILLAGE

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ABSTRACT

In a field experiment initiated in 1978, on a silty loam, silage corn was cropped for 9 years under 3 tillage systems; reduced tillage (T_1), reduced tillage plus soil ridging in the spring (T_2), conventional tillage including plowing (T_3). Aggregate stability measured from wet sieving of dry and moist aggregates the 5^{th} and the 7^{th} year indicates that both T_1 and T_2 favor larger mean weight-diameter than T_3 in the arable layer. Organic matter content of the larger aggregates measured the 7^{th} year is higher in the ridge than in the annualy plowed treatment. Water infiltration rate measured the 3^{rd}, 6^{th} and 8^{th} year shows constant decrease over years at the 5cm tested depth and a partial increase over years at the 20cm tested depth. The ratio of the infiltration rates between 5cm and 20cm depth is lower in the 8 years old corn field than in the control 11 years old grass meadow. Although tillage systems affected corn plant population in 1980, 83 and 84, dry matter yield of silage corn was affected only in 1983.

INTRODUCTION

Corn (*zea mays*) harvested for silage is currently grown on a monoculture basis on many Québec dairy farms. Moldboard plowing in the fall, immediately after manure spreading, and harrowing twice or more times in the spring to prepare the seedbed is the usual tillage practice. Soil degradation is expected to occur in these corn fields (Martel and MacKenzie, 1980). Since crop rotation does not attract a majority of farmers, conservation tillage has to be evaluated for silage corn monoculture. Soane and Pidgeon, (1975) in their review on physical conditions of field soil under different tilage systems demonstrated the potential for the reduced tillage system to improve soil tilth and structure and to protect the upper part of the seedbed against surface compaction and crusting. In colder climate it is even recommanded by Burrows, (1983) to grow corn on ridges since wetter and colder seedbeds result from reduced tillage particularly if trash is abundant and soil is poorly drained. Research on tillage systems with silage corn has been very scarced and of short duration (Tisdall and Adem, 1986), Stibbe, and al., 1980). To compare the long term effects of reduce tillage (flat and ridge) and of conventional tillage on soil properties and silage corn growth, a field experiment was set up for a ten years period in the fall of 1978.

MATERIAL AND METHODS

Soil under study is a Neubois silty loam characterized by a dense subsoil, a very poor internal drainage, a soil structure sensible to surface crusting and slaking. Previous crops were mixed hay in 1977 and silage corn in 1978. The three tillage systems tested with 5 replications in randomized block design are: (T_1) reduced tillage limited to 2 passages of field cultivator (spring tines) in spring, 7cm deep; (T_2) reduced tillage the same as T_1 plus soil ridging, 15cm height, before planting; (T_3) conventional tillage (fall moldboard plowing, 18cm deep, followed by 2 passages of field cultivator in the spring, 7cm deep). Spring secondary tillage was done the day before planting. Row spacing was 80cm from 1979 to 1983 and 76cm from 1984 to 1987. Annual fertilization was uniform at 200 kg/ha of N, P_2O5 and K_2O. All the tillage, seeding and harvesting were done with medium size farm machinery. Aggregates stability was measured by Yoder type wet sieving apparatus, with sieve openings of 5; 2; 1 and 0,2 mm. Aggregates between 5 and 8mm diameter were previously prepared by hand crushing of either air dry clods(1983) or field moist clods (1985-86). Mean weight-diameter is calculated using the method of Youker et al., (1956). Water infiltration rate was measured by using a single ring, constant head (3,5 cm) permeameter in auger holes, 5 and 20 cm deep, which cross-sectional area was 80 cm^2. Measurements were done in late spring, mid summer and fall. Volume of water infiltrated was 1000 ml, excepted for 1986 when it was reduced to 500 ml. Bulk density was measured with a portable Troxler nucleo-densimeter at different times in the growing season. Yields were taken on two 22 m long rows.

RESULTS AND DISCUSSION

Conventional tillage system shows the lowest aggregates stability (table I) both at 0-7cm and 9-16cm depths, the 7^{th} year. On the long term, ridge tillage may be more favourable to aggregates stability than reduced tillage alone because all the roots, lived and decayed, are concentrated in the narrow ridge (35cm wide at its base). Bauder et al.,(1985) after 5 continuous years of grain corn under conventional, conservation, reduced and ridge tillage systems observed that maximum root distribution occured in the ridge. Data from the meadow are also indicative of the effect of root distribution on aggregate stability since in this case the grass roots are distributed mostly near the surface. This also could explains why the 3 tillage systems have higher mean weight-diameter than the meadow at similar 18-25cm depth which is below the usual plow depth.

Tillage systems had no effect on the organic matter content of the Ap layer when the whole soil was considered. However organic matter content of large aggregates (5-8mm), is augmented by ridge tillage systems, probably as a result of better root distribution. Stone and Heslop (1987) suggest that improvement in soil structure below the depth of tillage from reduced tillage system may be a fonction of aggregation by organic as well as inorganic agent.

The field infiltration test in an auger hole although not standardized was retained to take into account the existing planar fracturation and biochannels in the soil profile. From table III it appears that continuous corn under T_1 and T_3 decreases the IR (infiltration rate) along years at the 5cm tested depth and partially increase IR at the 20cm tested depth. The difference in IR between the 5cm and 20cm

TABLE I

Aggregates mean weight diameter, the 5th and the 7th year of corn monoculture and on an adjoining meadow unplowed for 11 years on the same Neubois soil series.

Year	depth (cm)	Aggregates mean weight diameter (mm)				F test
		T_1	T_2	T_3	Meadow	
1983 (5th)	0 - 7	5,33 a[1]	4,25 b	4,39 b		**[2]
corn	9 -16	5,47 a	4,4 b	4,65 b		*[3]
	18 -25	5,23	4,72	4,78		n.s.[4]
1985 (7th)	0 - 7	3.72 a	4,26 a	2,27 b		*
corn	9 -16	3,90 b	4,88 a	3,38 b		**
	18 -25	3,86	4,62	3,55		n.s.
1986	0 - 7	-	-	-	4,74	
	9 - 16	-	-	-	3,28	
	18 - 25	-	-	-	2,79	

(1) data followed by the same letter are not significantly different.
(2) ** significative at the 99% confidence level.
(3) * significative at the 95% confidence level.
(4) n.s. non significative at the 95% confidence level.

TABLE II

Organic matter content measured the 3rd, 7th and the 8th year of corn monoculture, either on whole soil or on 5 to 8 mm diameter moist aggregates

Year	depth(cm)	organic mater %			F Test
		T_1	T_2	T_3	
1981 (3rd year)					
whole soil	0 - 7	5,2	4,9	4,8	n.s.[1]
	9 - 16	5,3	5,1	4,6	n.s.
	18- 25	5,6a[3]	4,6b	4,7b	**[2]
1986 (8th year)					
whole soil	0 - 7	5,4	5,4	4,8	n.s.
	9 - 16	5,4	5,4	4,7	n.s.
	18- 25	5,4	6,6	5,4	n.s.
1985 (7th year)					
aggregates	0 - 7	4,1ab	4,6a	3,9b	*
	9 - 16	3,9ab	4,3a	3,7b	*
	18- 25	3,7	3,9	3,5	n.s.

(1) non significative at the 95% confidence level.
(2) significative at the 95% confidence level.
(3) data followed by the same letter are not significantly different.

TABLE III

Infiltration rate of water (IR). Data presented are logarithmic means of 10 or more individual tests.

Year	depth (cm)	infiltration rate (millimeter/minute)			
		T_1	T_2	T_3	Meadow(1)
1981 (3rd)	5	60	-	36	
1984 (6th)	5	27	-	7,9	
1986 (8th)	5	5,7	15	12	4,1
1981	20	4,5	-	0,5	
1984	20	17	-	4,7	
1986	20	1,5	1,5	4,1	0,07

(1) IR in eleven years old grass meadow located beside corn field.

TABLE IV

Soil dry bulk density measured after eight years of corn monoculture, 26,50 and 74 days after seedbed preparation.

Depth (cm)	Time after seedbed prep. (days)	Bulk density ($Mg\ m^{-3}$) T_1		T_2		T_3		F test
0-5	26	1,04	abc(1)	0,99	c	1,01	bc	
	50	1,09	a	1,03	abc	1,03	abc	
	74	1,08	ab	0,98	c	0,99	c	*(2)
5-10	26	1,35	a	1,21	c	1,25	bc	
	50	1,38	a	1,23	bc	1,27	bc	
	74	1,30	ab	1,19	c	1,23	bc	**(3)
10-15	26	1,42	a	1,39	a	1,35	ab	
	50	1,41	a	1,39	a	1,33	ab	
	74	1,40	a	1,37	a	1,24	b	*
15-20	26	1,36	abc	1,39	ab	1,27	c	
	50	1,42	a	1,38	ab	1,26	c	
	74	1,35	abc	1,40	ab	1,30	bc	**

(1) data followed by the same letter are not significantly different.
(2) * Significative at 95% confidence level
(3) ** Significative at 99% confidence level

TABLE V

Corn plants population measured after complete emergence, from the second to the ninth year of corn monoculture.

year	Corn plants per ha T_1	T_2	T_3	F. test
1980	53200 b(1)	58900 a	59100 a	*(2)
1981	57800	63200	60800	n.s.
1982	59700	59700	61600	n.s.
1983	38700 b	55600 a	44900 a	**(3)
1984	79400 b	90200 a	86100 ab	*
1985	52300	63000	59800	n.s.(4)
1986	90700	93800	93300	n.s.
1987	91300	92000	93600	n.s.

(1) data followed by the same letter are significantly different.
(2) * significative at the 95% confidence level.
(3) ** significative at the 99% confidence level.
(4) n.s. non significative at the 95% confidence level.

TABLE VI

Corn silage yield during the nine years of corn monoculture.

year	Dry matter (Mg/ha) T_1	T_2	T_3	F test
1979	11,2	11,3	10,8	n.s.
1980	9,88	10,1	10,4	n.s.
1981	11,2	11,5	10,5	n.s.
1982	10,2	11,1	10,9	n.s.
1983	7,32 c(1)	8,64 a	7,80 b	**(2)
1984	10,1	11,0	9,16	n.s.(3)
1985	8,17	8,73	8,64	n.s.
1986	5,43	5,67	4,91	n.s.
1987	12,5	13,2	12,6	n.s.

(1) data followed by the same letter are not significatly different
(2) ** significative to the 99% confidence level
(3) n.s. non significative to the 95% confidence level

tested depth is narrower in the 8 years old corn field under the three tillage systems than in the 11 years old grass meadow probably as a result of root distribution and structure development.

Bulk density measured after 8 years of continuous silage corn, (table IV) shows that: (1) time elapsed after seedbed preparation increases bulk density only in 0-5cm depth for T_1; (2) at 5-10cm depth, soil in T_1 has a higher bulk density than in T_2 and T_3; (3) at the 10-20cm depth soil in T_3 has occasionally a lower bulk density than either T_1 or T_2. These occasional differences in bulk density below 10cm depth are probably due to wheel-induced compaction from previous years and also due to the erratic effect of the moldboard plow. Corn plant population after complete seedling emergence, was affected by tillage systems only 3 out of the 9 years (table V) and in only one corresponding year, 1983, did the decrease in plant population lowered the yield of silage (table VI). Extremely low yields in 1986 are a result of a shortage of corn heat units that year.

CONCLUSION

Continuous silage corn grown with reduced tillage systems on level seedbed and on ridges has proved to be a successfull practice even if no manure was used. Ridge tillage has a small adventage over flat reduced tillage on poorly drained soil in wet spring like we experienced in 1983. On the long term conventional tillage system is detrimental to structure. Farmers should be attracted by the reduce tillage systems for its economic advantages.

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SINGLE AND DUAL PROBE NUCLEAR INSTRUMENTS FOR DETERMINING WATER CONTENT AND DENSITY OF A LAYERED CLAY LOAM SOIL

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ABSTRACT

The objective of this report was to characterize the shrinkage and swelling of a clay loam soil containing a substantial proportion of smectite and to evaluate the usefulness of commercially available single and dual nuclear probes for soil water and density measurements in such materials. The single probe was evaluated both in a packed bin and in the field. It gave quite good results although soil water determinations were primarily determined by near-surface contents. This was not a problem with the dual probe where the source and detector of neutrons were located much closer to the region where γ-ray attenuation was being recorded.

INTRODUCTION

Changes in the attenuation of gamma (γ) rays provide a rapid method for measuring a soil's wet bulk density (weight of dry soil plus water per unit volume) if an adequate calibration has been developed (Erbach, 1987). Rawitz et al. (1982) observed that factory calibration of a commercial dual-probe instrument using metal blocks yielded inappropriate dry densities for coarse-textured Israeli soils; they recommended field calibration. Gameda et al. (1987) recently published an analysis of commercially available single and dual probe instruments and reiterated the need for in situ calibration. The purpose of this report was to investigate the performance of similar instruments for studies of wet density and volumetric water content relationships in a swelling soil.

MATERIALS AND METHODS

The Ap horizon of a cropped Orthic Humic Gleysol (Dalhousie Association) was used in this study. It contains 32% sand and 37% clay, of which about 37, 13 and 9% are smectite, vermiculite and mica, respectively (Ross et al., 1987). The remainder of the fine fraction consists of primary minerals (32%) and noncrystalline materials. The soil contains 1.5% combustible total carbon, 0.11% total nitrogen and has a pH of 5.4 in 0.01 M $CaCl_2$.

Approximately 600 kg of the soil was air-dried and sieved to pass a 6-mm sieve. Standard Proctor tests were conducted on this material at air-dryness (0.042 kg kg^{-1}) and at water contents of 0.15 and 0.233 kg kg^{-1}. Final dry densities at these three water contents were 1470, 1700 and 1511 kg m^{-3}, respectively. Shrink-swell behaviour of the sieved material was studied by packing small cylindrical cores (54 mm

I.D. x 30 mm) with sufficient air- dry soil so that on saturation, core dry densities were either 1091±4 or 1246±42 kg m^{-3}. The cores were equilibrated either on glass beads maintained at a matric potential (ψ) of -10 kPa, or on ceramic plates pressurized at 100, 500 or 1500 kPa. After equilibration, the cores were removed, weighed and a known volume of dry, uniform glass beads was added to each core to estimate shrinkage. All cores were then oven-dried at 105°C for several days after which total shrinkage was determined, again using glass beads.

A bin (1.09 x 0.62 x 0.45 (deep) m) constructed from wood and located in a greenhouse was packed with the sieved Dalhousie soil adjusted to a water content of 0.135 kg kg^{-1}. A bottom layer, 0.125 m thick was packed with a target final wet density of 1500 kg m^{-3}. Above this layer five 0.05-m-thick layers were packed with target wet densities of 1450, 1400, 1350, 1300 and 1250 kg m^{-3}. Pairs of stainless steel rods were installed 0.05 m apart through one side-wall at depths of 0.025, 0.076, 0.125, 0.178, 0.229 and 0.275 m below the soil surface. These rods were used to measure volumetric water contents by time domain reflectometry (TDR) using cable tester equipment (Topp and Davis, 1985). The bin was then saturated, covered with insulation and plastic, and allowed to drain. Substantial swelling and shrinking occurred during the first cycle. Thus, soil corings taken at termination of the experiment were used for instrument calibrations. Measurements of soil water contents using TDR, and γ-ray (DC) and neutron (MC) counts using a single probe Troxler unit (model 3411) and a dual probe CPN Strata gauge were made over two drying and wetting cycles. Gameda et al. (1987) have described some of nuclear probe characteristics. Counts were also taken with the bin filled with water. Standard counts for γ-rays (DS) and neutrons (MS) were taken according to the manufacturers' specifications. Source strengths and source-detector geometries for both instruments were studied by mounting various thicknesses of plate glass having a density of 2519±3 kg m^{-3} between sources and detectors.

Factory calibration for wet densities ρw were tested using:

$$\rho w = A + B \ln(DS/DC) \qquad (1)$$

where A and B are coefficients related to source strength, geometry of the source and detector (path length), and the γ-ray extinction coefficients for the soils. Both A and B were determined by least squares regression using data for the bin filled both with soil and water.

RESULTS AND DISCUSSION

Total volume change of the small cores on drying from saturation to oven-dried amounted to 27.9 and 24.2 % for cores initially at a dry densities of 1090 kg m^{-3} and 1246 kg m^{-3}, respectively. Of these total changes about 90% occurred between saturation and ψ of -1500 kPa. Wires et al. (1987) observed that about 85% of the shrinkage of a similar soil in an undisturbed state occurred over this same range in ψ. These results emphasize the need for care in the interpretation of soil bulk density measurements. Wet and dry densities behaved oppositely on drying (Table 1). For the more loosely packed cores, there was some indication of structural shrinkage (Shirk, 1954) between saturation and ψ=-10 kPa; such a phase was not apparent for the more dense cores. On the other hand, the wet density of the loosely packed cores decreased more on drying than did the packed cores. These results indicated that consistently decreasing γ-ray counts should be observed during drying.

Table 1. Best-fit linear regressions of wet and dry densities as a function of volumetric water contents between saturation and -1500 kPa matric potential for loosely-packed(1090 kg m^{-3}) and more densely packed (1246 kg m^{-3}) cores.Standard errors are shown in brackets.

	Loose			Packed		
	Intercept	Slope	r^2	Intercept	Slope	r^2
	kg m^{-3}			kg m^{-3}		
Dry density	1554 (30)	-0.774 (0.028)	0.956**	1729 (50)	-0.867 (0.064)	0.863**
Wet density	1554 (30)	0.286 (0.029)	0.779**	1729 (50)	0.133 (0.064)	0.130*

A wide range of neutron and γ-ray counts were recorded over the drying cycles (Table 2). For example, at a depth of 0.025 m, water content varied from 0.05 to 0.33 m^3 m^{-3} with a mean and standard deviation (s) of 0.167 and 0.121 m^3m^{-3}, respectively. The range was marginally less at depth; at 0.275 m the mean was 0.339 and s was 0.116 m^3 m^{-3}. Soil γ-ray counts (DC) using the dual probe exhibited CV's (coefficients of variation) ranging from 12% at 0.05 m to 15% at 0.25 m. Transformation of DC to ln (DS/DC) introduced considerably more variation, as indicated by CV's varying from 40% near the surface to 23% at 0.25 m. With the single probe, DC CV's varied from 11 to 23 %, while for the log-transformed variable, ln(DS/DC), CV's ranged from 14 to 68%. Over the experimental period, the CV for DS was less than 1%. Thus, it is the transformation which introduces the variation. Neutron count ratios for the single probe had a CV of 41% over the drying cycles; the CV for MS was 4%. Statistical analyses showed that dual- and single-probe DC's decreased by about 1.3 and 1.2 %, respectively, for each % decrease in water content confirming the hypothesis that γ-ray attenuation descreased as the soil shrank.

Regression of TDR water contents against neutron count ratios (Table 3) indicated that the best fit for the single probe instrument, where both the source and the detector remain at the surface, was with water content in the near-surface zone. However, good fits were obtained at all depths. Good results were also obtained with the dual probe; the same regression equation worked equivalently well for depths greater than 0.15 m.

Best-fit estimates of A and B for use in eqn. (1) are tabulated in Table 4. Very similar results were obtained when Table 4 values and the factory-supplied calibrations were used to predict wet densities. Correlation of predicted and measured wet densities of cores from both Dalhousie clay loam and sand yielded virtually identical relationships. Regression using the factory-supplied coefficients gave an equation with $r^2=0.799$*** with a standard error of 73 kg m^{-3}; estimates obtained using table 4 values gave a marginally better r^2 (0.805***), but a slighty greater error of 79 kg m^{-3}. The CV's with both methods were less than 5%. Field tests with the dual probe have not been completed.

Table 2. Soil water, γ-ray ratio and neutron ratio counts means and standard deviations for bin packed with Dalhousie clay loam.

	Dual Probe			Single Probe	
Depth to source	Volumetric (TDR) water content	ln (DS/DC)	MC/MS	Volumetric (TDR) water content	ln (DS/DC)
m	m^3 m^{-3}				
BS¶	-	-	-	0.162±0.117	0.519±0.140
0.05	0.182±0.115	0.332±0.125	0.222±0.089	0.168±0.121	-0.721±0.113
0.10	0.230±0.120	0.308±0.131	0.903±0.451	0.208±0.113	-0.785±0.110
0.15	0.238±0.142	0.367±0.139	1.966±0.979	0.254±0.117	-0.605±0.114
0.20	0.301±0.111	0.492±0.155	2.875±1.067	0.289±0.112	-0.255±0.126
0.25	0.388±0.062	0.656±0.153	3.910±0.742	0.303±0.112	0.235±0.159
0.30	0.451	0.828	4.804	0.339±0.116	0.269±0.108

BS¶ refers to Backscatter mode

Table 3. Best-fit regression parameters for predicting volumetric water content with (TDR) from neutron count ratio (MC/MS).

	Single Probe				Dual Probe				
Depth	Intercept	Slope	r^2	St error	Depth	Intercept	Slope	r^2	St error
m					m				
BS¶	-0.138	1.180	0.984	0.015					
0.025	-0.112	1.029	0.990	0.012	0.05	-0.024	0.775	0.981	0.011
0.075	-0.034	0.909	0.966	0.020	0.10	0.044	0.172	0.891	0.031
0.125	-0.005	0.996	0.891	0.039	0.15	0.011	0.105	0.725*	0.073
0.175	0.033	1.040	0.841	0.044	0.20-0.30	0.042	0.084	0.985	0.014
0.225	0.060	0.930	0.826	0.049					
0.275	0.072	0.985	0.845	0.050					

* indicates significant regression at p 0.05; all other regressions significant at p 0.001

¶ refers to Backscatter mode

Tables 4. Best-fit estimates of A and B coefficients used in equation 1 to predict soil wet density.

Depth of probe	Single Probe A	Single Probe B	Dual Probe A	Dual Probe B
m				
Backscatter	997.	596.	-	-
0.05	2059.	918.	1153.	0797.
0.10	2082.	865.	1147.	0598.
0.15	1856.	751.	1155.	0555.
0.20	1559.	621.	1161.	0533.
0.25	1316.	530.	1161.	0571.
0.30	1116.	473.	1205.	0670.

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MICROBIAL ACTIVITY AND N CYCLING AS REGULATED BY SOIL WATER-FILLED PORE SPACE

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ABSTRACT

Microbial activity and N tranformations in repacked cores of 18 major USA surface soils of varying texture, organic carbon content, and previous management were closely associated with the proportion of soil pore space filled with water (WFPS). Soil respiration for 16 soils increased with increasing water content attaining maximum values between 55 and 61% WFPS after which further increase of water resulted in decreased respiration. Changes in soil nitrate levels over 4 weeks were related to soil WFPS in a manner similar to that of soil respiration but major losses of nitrate (7 to 90 mg/kg soil) for most soils occurred where soil WFPS exceeded 75%. Nitrate loss coincided with microbial denitrification which increased exponentially when soil WFPS exceeded 70 to 75%. Microbial responses to WFPS differed for two highly weathered Hawaiian soils for which respiration and nitrate accumulation increased with WFPS up to 90% with little denitrification loss of N. Soil WFPS appears useful for simultaneously evaluating the effects of management-related changes in soil bulk density and water content on aeration-dependent microbial processes.

INTRODUCTION

Over the past two decades shifts to reduced tillage have been stimulated by needs to decrease fuel and labor inputs , to reduce soil erosion losses, and to enhance production in climatic areas where water is limiting crop growth. The physical environment of reduced-tillage surface soils, however, is often cooler, wetter, and more compact than that of conventionally tilled soils (Mielke et al., 1986). These differences in the soil physical environment with reduced-tillage soils are often associated with lower net mineralization of soil N and greater gaseous N losses through denitrification as compared with cultivated soils (Fox and Bandel, 1986). Consequently, reduced tillage can limit crop growth on fine-textured or imperfectly drained soils, particularly during wet growing seasons (Blevins, 1984). Doran and Linn (1984) identified the proportion of soil pore space which is water filled as a major factor determining soil aerobic microbial activity and denitrification in tillage management comparisons at several USA locations.

A more complete understanding is needed of how changes in soil water status and porosity influence microbial activities and N cycling for a range of soil types. Previous research has demonstrated the importance of balance between soil air and water in determining aerobic and anaerobic microbial activity. Aerobic microbial activity increases with soil water content until a point is reached where water displaces air and restricts the diffusion and availability of oxygen to sites of microbial activity. The results of many studies, involving a wide range of soil types, indicate that a soil water content equivalent to 60% of a soil's water holding capacity delineates the point of maximum aerobic microbial activity (Greaves and Carter, 1920; Linn and Doran, 1984).

The present study was initiated to evaluate the influence of soil water-filled pore space on aerobic and anaerobic microbial processes important to N cycling in soil for a range of surface soils varying in texture, organic matter status, and previous management. Water-filled pore space was chosen as a practical index of soil aeration status since it integrates the effects of tillage on both soil porosity and water content, requires measurement of only soil bulk density and gravimetric water content, and thus can be utilized by a greater number of researchers and farmers.

MATERIALS AND METHODS

Eighteen soils for experimentation were collected from surface soil A horizons of benchmark sites in Major Land Resource Areas in the USA and represented 9 of 10 taxonomic soil orders. The soils varied in texture, organic matter content, and management history with respect to cropping, native vegetation, and soil cultivation (Table 1). To reestablish soil biological activity after collection and storage and a common basis for evaluating physical/biological interactions all soils were pre-conditioned before experimentation by cropping to oats (*Avena sativa* L.). Where necessary, soils were limed to achieve a pH of 6.5 to 7.5 and amended with N or P to narrow factors limiting plant and microbial growth to those of primary interest-namely soil aeration and water content.

Soils were passed through a 2mm mesh sieve and hand compacted to bulk densities representative of natural reconsolidation values for each soil as estimated after cropping and several wetting and drying cycles in the greenhouse and by subjecting soils, at a water tension of 10 kPa, to a pressure equivalent to a normal equipment load in the field (47.9 kPa). Experimental treatments for each of the 18 soils consisted of five soil water content levels equivalent to water-filled pore spaces of 30, 45, 60, 75, and 90%. Soil water-filled pore space, synonymous with relative saturation, was calculated from the quotient of soil volumetric water content divided by total soil porosity. Soil porosity was calculated from soil bulk density assuming a soil particle density of 2.65 g/cm^3. After adjustment of soil water content the repacked soil cores, contained in 100 mL glass beakers, were placed in 1.9L sealed glass vessels and incubated for four weeks at 25°C.

Soil respiration was estimated from carbon dioxide produced in incubation vessel headspace over the four week period. Soil denitrification was determined by measurement of nitrous oxide produced over the second to third week periods in incubation chambers to which 10% acetylene was added to block reduction to N_2. Net mineralization of N was determined through comparison of initial and final ammonium and nitrate levels in 2*M* KCl soil extracts. Further details of chromatographic analysis of soil gases and soil mineral N levels are given by Linn and Doran (1984).

RESULTS

Soil respiration in repacked cores for 16 of the 18 soils tested responded in a similar manner to the proportion of soil pore space filled with water (Fig. 1). Soil respiration increased 20 to 60% with increasing water content attaining maximum

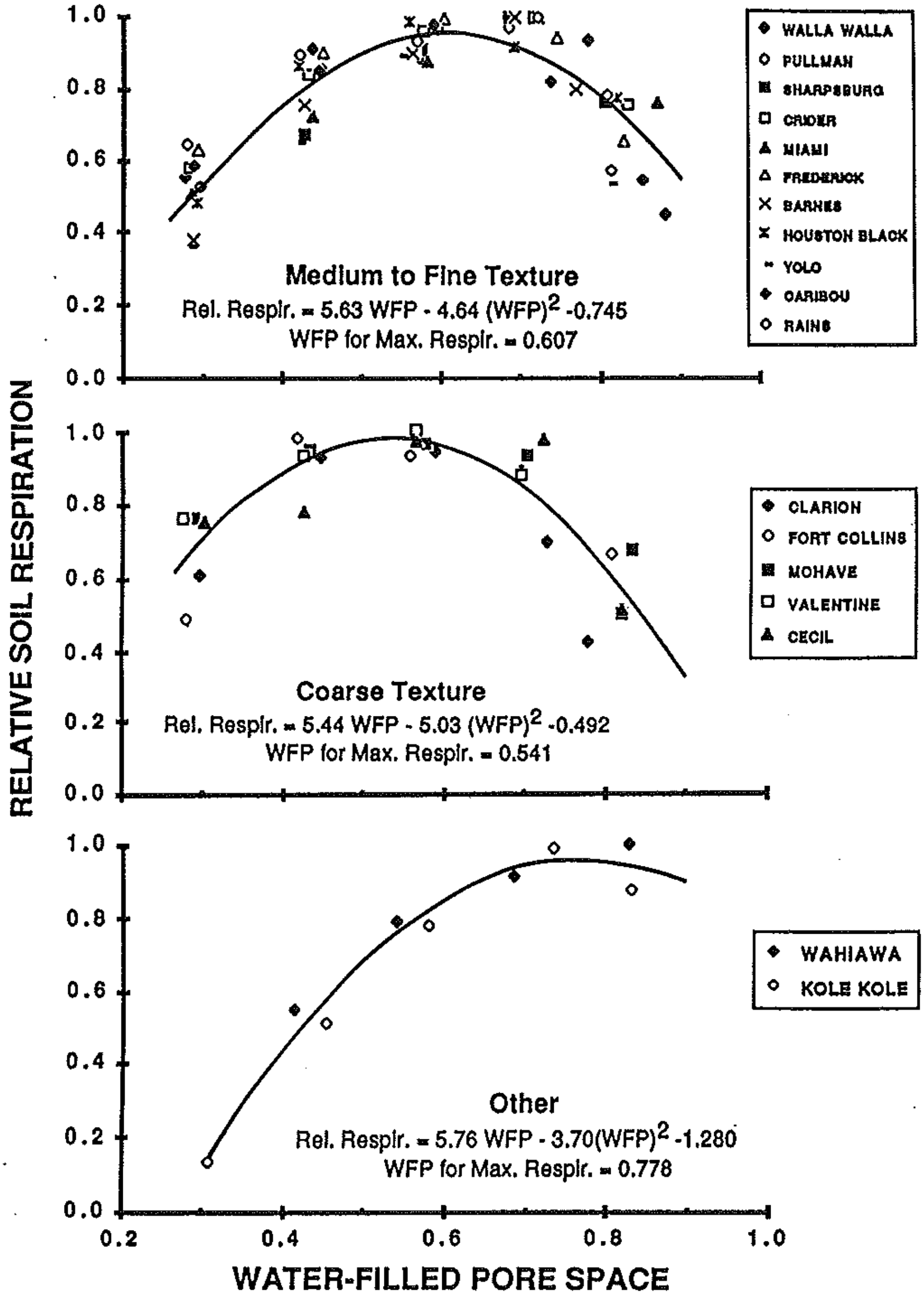

Fig. 1. Relationship between soil water-filled pore space and relative soil respiration for repacked cores of 18 benchmark soils grouped by soil texture or structure.

values between 55 and 61% WFPS after which further increases of water to between 80 and 90% WFPS resulted in decreases in respiration of 20 to 60%. The respiration data presented in Fig. 1 were expressed as relative comparisons to the maximum carbon dioxide produced from each soil to normalize large differences in soil organic C and other chemical characterisics between soils and permit better evaluation of the direct effects of soil WFPS among soils. A quadratic model of WFPS with relative soil respiration within three soil groupings provided an excellent fit for the experimental data (R^2=0.58 to 0.87, p<0.0001). Response of coarse textured soils, having a sand content > 50%, varied somewhat from that of medium to fine textured soils and the WFPS for maximum respiration, as determined from the first derivative of the quadratic relationship, was somewhat lower than finer textured soils (54.1% versus 60.7%). Also, increases in relative respiration for coarse textured soils with increasing water content were somewhat smaller at WFPS below the optimum for maximum respiration and decreases with increased water above the optimum were somewhat greater than those in medium to fine textured soils. Soil respiration of two highly weathered Hawaiian soils, which had a very fine granular structure, responded differently than other soils and respiration in these soils increased until soil WFPS exceeded about 78%.

Changes in soil mineral N over the four week incubation period were related to to soil WFPS in a manner similar to those for soil respiration. Soil ammoniun levels were significantly influenced by soil water content for only four soils where ammonium-N contents at WFPS > 80% were 3 to 17 mg N/kg soil greater than those at lower values of WFPS. Since soil mineral N changes for most soils were predominantly reflected by changes in nitrate-N only these data are presented in Table I. Maximum accumulation of nitrate-N over the four week incubation occurred at WFPS of 57 to 72% for medium to fine textured soils, 44 to 59% for coarse textured soils, and 74 and 83% for the two Hawaiian soils. Major losses of nitrate-N of from 7 to 90 mg N/kg soil for most soils occurred where WFPS exceeded 75%. These losses of nitrate-N, equivalent to 8 to 63% of the amounts accumulated under presumably more aerobic conditions at lower WFPS values, coincided with anaerobic microbial denitrification which increased exponentially when WFPS exceeded 70 to 75% (Fig. 2). Nitrate accumulation in the highly weathered Hawaiian soils increased with WFPS up to 74% for the Kole Kole loam and 83% for the Wahiawa clay with no significant denitrification losses of N from either soil at average WFPS values of 84 and 82%, respectively.

DISCUSSION

For a wide range of soils the percentage of soil pore space filled with water appears well correlated with aerobic and anerobic microbial activity and associated processes of respiration, mineralization, and denitrification. Results of this study support earlier findings with fewer soils that aerobic microbial activity increases in a linear manner with increasing water content between 30 and 60% WFPS and then declines above 60 to 70% WFPS as a result of further water presenting a barrier for diffusion of oxygen to soil microorganisms (Linn and Doran,1984). Our findings agree well with those of Stanford and Epstein (1974) who found that relative mineral N accumulation in 9 texturally different soils increased linearly with relative soil water content to an optimum level above which N accumulation declined, presumably as a result of increased denitrification. In their study, losses of nitrate occurred when estimated soil WFPS exceeded 80 to 90%.

In earlier research 80% WFPS was proposed as the point at which significant

Table 1

Soil organic C content, experimental soil bulk density, and soil nitrate-N change in 4 weeks as influenced by water-filled pore space (WFPS) for repacked cores of 18 surface soils.

Soil series	Organic C (%)	Bulk density (Mg/m3)	Change in nitrate-N (mg/kg soil) for median WFPS of 0.30	0.44	0.57	0.74	0.83	LSD 0.05
Walla Walla sil	1.14	1.10	18	20	23	11	-13	13
Barnes l	2.34	1.20	-5	3	3	9	-13	NS
Pullman sicl	0.96	1.10	13	14	15	14	-8	6
Sharpsburg sicl	1.80	1.10	4	9	7	12	-1	NS
Houston Black sic	1.61	1.00	12	16	16	16	0	10
Crider sil	2.12	1.10	-55	-47	-42	-42	-78	NS
Miami sil	1.26	1.20	8	16	18	11	7	7
Yolo sil	1.33	1.20	8	11	15	17	8	NS
Frederick sil	2.21	1.10	-44	-30	-47	-33	-82	NS
Rains sil	3.29	1.10	24	35	28	33	-7	15
Caribou l	2.55	1.00	34	43	44	27	-46	16
Clarion sc	1.40	1.20	11	11	12	2	-15	12
Valentine s	0.90	1.35	6	6	5	3	-24	6
Mohave scl	0.73	1.20	18	19	12	15	2	8
Fort Collins scl	0.81	1.20	12	10	12	10	5	NS
Cecil sl	3.14	1.10	15	14	17	12	-42	16
Kole Kole l	3.46	1.10	-1	2	4	5	2	NS
Wahiawa c	1.30	1.10	3	16	18	20	22	5

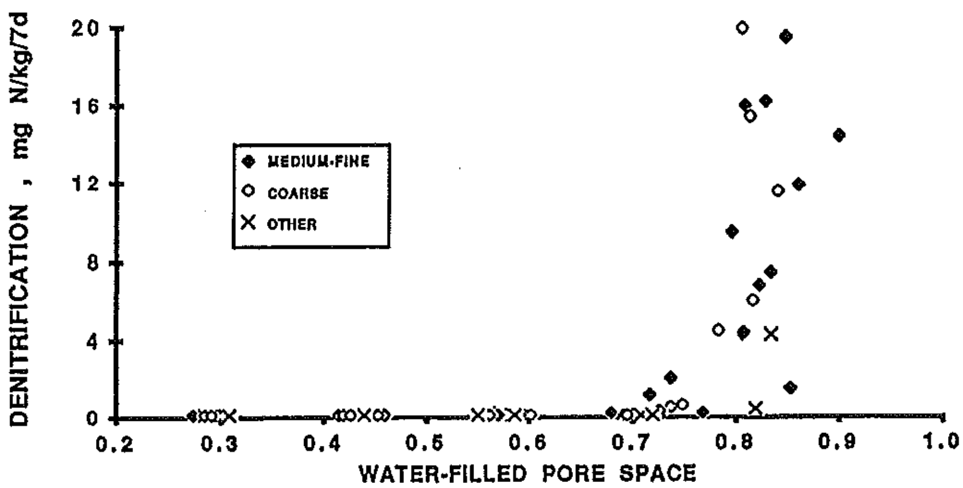

Fig. 2. Relationship between soil water-filled pore space and soil denitrification over 7 days for repacked cores of 18 benchmark soils grouped by soil texture or structure.

denitrification would occur in most soils, given adequate supply of available C and nitrate-N, and that at 60% WFPS little or no denitrification would occur (Linn and Doran, 1984). This postulation was confirmed in the present study for a wide range of soils in which denitrification was absent below 63% WFPS but increased exponentially at WFPS exceeding 70 to75% in all but two Hawaiian soils which differed considerably in soil physical properties and presumably pore-size distributions. Grundmann and Rolston (1987), working with one of the same soils as used in our study, found relative water saturation (synonymous with WFPS) exponentially related to denitrification between 62% WFPS, the point at which no denitrification occurred, and 100% WFPS where denitrification was assumed to be maximal.

CONCLUSIONS

The proportion of soil pore space filled with water appears useful for simultaneously evaluating the effects of soil bulk density and water content on aeration-dependent microbial processes as related to tillage-induced changes in the soil physical environment. The consistency of relationship between soil WFPS and microbial activity for a wide range of soils enhances predictions of tillage management effects on aeration-dependent microbial processes over a range of climatic and soil drainage conditions. Of particular importance is the utility of WFPS to predict potential losses of soil and fertilizer nitrate-N through microbial denitrification.

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CORN ROOT DISTRIBUTIONS AS A FUNCTION OF TILLAGE AND RESIDUE MANAGEMENT

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ABSTRACT

Tillage and residue management influences on corn rooting patterns were measured after 7 y of continuous corn with annual reapplication of treatments on a silt loam Mollisol in northern Corn Belt of U.S.A. Tillage x residue treatments included no tillage, chisel plow, and moldboard plow, with and without residues. Roots were sampled at the V10 (10-leaf) and R1 (100% silk) growth stage. Maximum root length densities (RLD) were associated with the chisel plow treatment in the absence of residue and developed more slowly under no tillage. Root mass accumulated more slowly than did RLD and increased 10X between the V10 and R1 growth stages. Residues stimulated early root length and mass accumulations and concentrated roots in the surface (0 to 0.15 m) soil, particularly for the no tillage treatment. Below 0.15 m, lateral root distributions varied with time and tillage x residue combinations. Generally, coarser roots were present in the no tillage treatment without residue; the difference did not occur in the presence of residues.

INTRODUCTION

Root growth and distribution directly affects plant utilization of nutrients and therefore plays a key role in movement of applied agricultural chemicals to groundwater. Spatial quantification of plant root distributions are laborious, expensive, and quite variable. Hence, information describing root configurations under various tillage and residue management systems is fragmentary, particularly for cooler climates. Allmaras et al. (1975) noted a maximum corn root length density (RLD) of 4.3 km/m^3 and pointed out the soil and climatic specificity of such measurements. Subsequently, Allmaras et al. (1987) reported that optimum corn rooting in conservation tillage systems can be achieved by residue placement depending on base soil temperature and water conditions. Barber (1971) observed deeper, finer, more extensive root systems with tillage _vs._ no tillage and that residues depress root growth in the upper 0.1 m of soil. On the other hand, Newell and Wilhelm (1987) observed that surface residue encouraged root proliferation in the top 0.15 m soil layer under drier conditions and, Anderson (1987) did not observe direct or specific effects of tillage on root diameter 9 y after tillage was established. The objective of this paper is to define rooting patterns of corn during the seventh year of continuous corn produced by various tillage x residue management systems.

MATERIALS AND METHODS

Root samples were collected during the seventh growing season from a continuous corn, tillage x residue field study. The Waukegan soil is a silt loam, Typic Hapludoll. Treatments consisted of the following tillage x residue combinations: i) no tillage without or with residue remaining on the soil surface, ii) chisel plow without or with partially incorporated residue, and iii) moldboard plow without or with incorporated residue. All areas received 100 kg N/ha preplant. Corn (Zea mays L, var. Pioneer 3780) was planted May 16. Root samples were taken 47 (10-leaf stage, V10) and 80 (100% silk stage, R1) days after planting. Soil was cored about four randomly selected plants in each treatment. Cores were extracted immediately adjacent to the plant and at 0.075, 0.15 and 0.3 m on a line normal to the row. The cores were segmented into 0.15 m sections and stored at $4^{o}C$. Roots were separated from soil by elutriation, picked free of non-root debris, and stored in 20% methanol solution. Roots, stained with basic fuschin, were floated on water and imaged with a linear array digitizing camera. Root length was determined by scanning the image by the line intersect approach. Root weights are expressed on a $65^{o}C$ basis. Root length and weight are quite variable, with respective mean coefficients of variation of 0.56 and 0.53. For this reason, data were grouped into six size ranges for analyses. Differences labelled as significant are significant at P = 0.10.

RESULTS AND DISCUSSION

Root Length Density (RLD): No Residue

Observed RLD (Fig. 1) for the six tillage x residue management systems at the V10 and R1 growth stages were approximately twice as high as those reported by Newell and Wilhelm (1987) in the fourth year of continuous corn. For the earlier growth stage (V10), RLD ranged from 1 to 25 km/m^3 and were greatest for the chisel plow treatment. This trend was still evident at the R1 growth stage. Recently, Newell and Wilhelm (1987) reported greater root length associated with chisel treatment compared to disc and no tillage at the V8 growth stage. The higher RLD (> 15 km/m^3) for the chisel plow treatment extended to the 0.75 m depth for sampling locations next to the plant (0 to 0.15 m) at the V10 growth stage. Generally, RLD decreased from the V10 to R1 sampling dates at depths below 0.45 m for the chisel plow treatment, possibly the result of a measured 5 to 7 % (w/w) soil water reduction that occurred over the same time interval, similar to findings of Mackay and Barber (1986). Unlike chisel plow, root development was not as extensive by the V10 stage of growth for no tillage and moldboard plow treatments and RLD continued to increase to the R1 growth stage. Significantly less root development occurred at all depths next to the plant in the no tillage treatment (V10 sampling) and this trend continued with time (R1) and distance from the plant. Slower development of root length in the no tillage treatment coincides with a trend of slower seedling emergence (Schneider and Gupta, 1985). Newell and Wilhelm (1987) noted that such growth differentials can continue through the growing season. RLD increases in the interrow were particularly evident for the moldboard plow treatment between V10 and R1 sampling dates, reaching 12 km/m^3 at a distance of 0.3 m from the plant and depths of 0.75 to 0.9 m.

Root Length Density (RLD): with Residue

The presence of residue resulted in significantly higher RLD for both no tillage and moldboard plow treatments at the V10 growth stage (Fig.

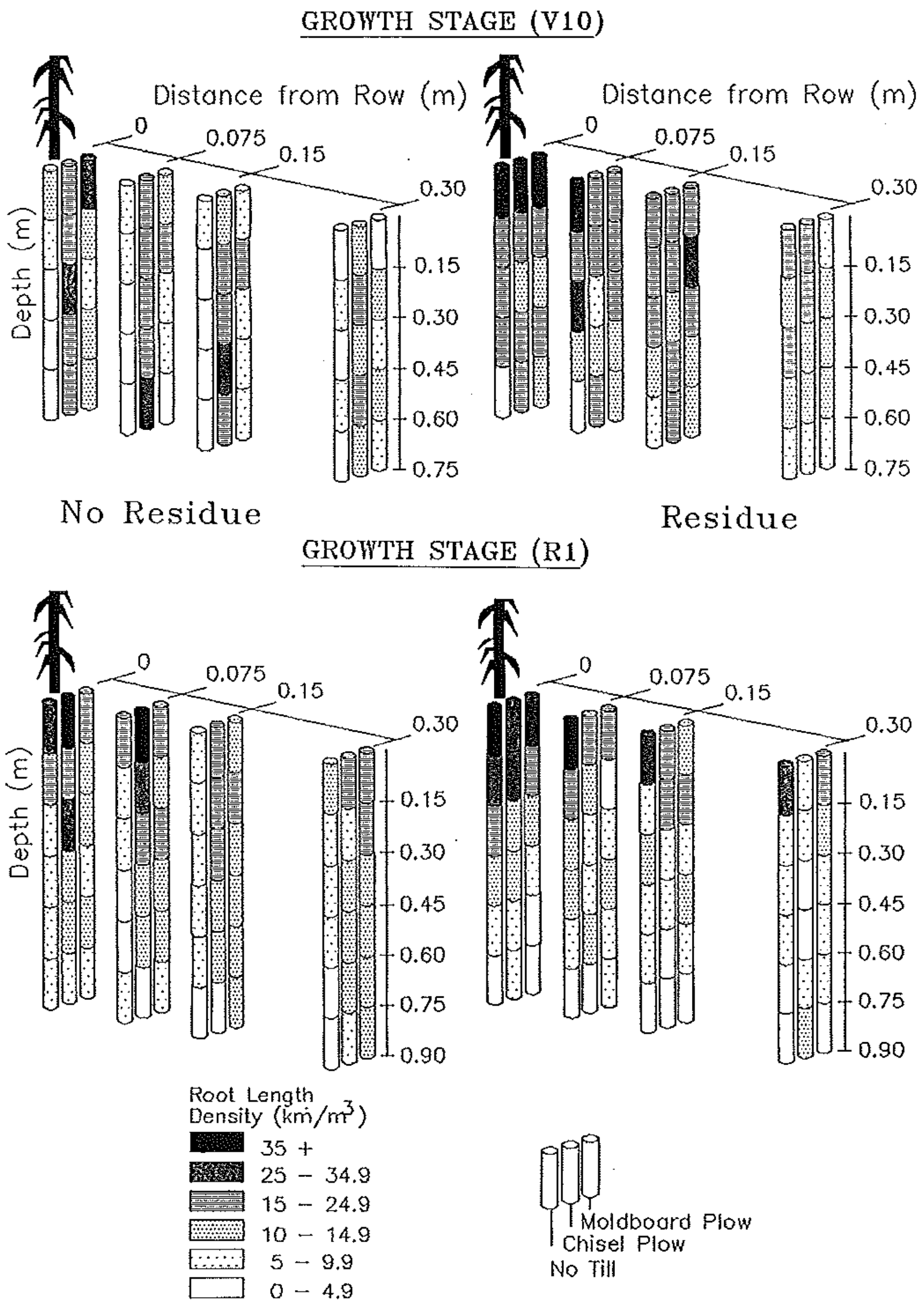

Fig. 1. Corn root length density at two growth stages following 7 years of continuous cropping, tillage, and residue treatments.

1). This effect of residue on RLD is contrasted to the work of Barber (1971) who noted greater root growth in the top 0.1 m of soil in the absence of residue. Enhanced RLD were not observed at the later R1 growth stage when compared with the no residue treatment. However, the presence of residues was associated with a differential concentration of root length in the upper 0.3 m of soil (particularly no tillage) compared to lower soil depths at the later R1 growth stage, probably a result of more favorable water regimes associated with residues. Below 0.15 m, RLD for the no tillage residue treatment were greater next to the plant and decreased with distance from the plant. A comparable decrease was not observed for the moldboard plow treatment. This effect of tillage on root distribution may impact corn production, during seasons of limited water (Allmaras et al., 1987; Newell and Wilhelm, 1987).

Root Weight Density (RWD): No Residue

Differences among tillage treatments as to root mass accumulations (Fig. 2), were not expressed as strongly as RLD differences at the V10 growth stage. The RWD increased by an order of magnitude between the V10 and R1 growth stages for surface sampling positions nearer the plant (0 to 0.075 m). Increased RWD (V10 vs. R1) were also noted at greater soil depths and distance from the plant. This was particularly evident for the moldboard plow treatment where significant RWD increases over the no tillage and chisel plow treatments were observed at the 0.3 m interrow position in the 0.15 to 0.6 m depth zone. On the other hand, Anderson (1987) has suggested that root growth below 0.14 m was not influenced by tillage.

Root Weight Density (RWD): with Residue

The presence of residue significantly increased RWD in the 0 to 0.15 m soil layer for all tillage treatments by the V10 growth stage (Fig. 2), which mirrors comparable RLD observations. This trend was also observed with depth. Root mass accumulations increased significantly between the V10 and R1 growth stages near the plant (0 to 0.3 m depth and 0 to 0.075 m distance) as was also true in the absence of residue. However, no RWD increases were found at greater depths and distances from the plant. This suggests that old roots were dying as fast or faster than new roots were formed in the interrow area in a pattern similar to observations of Mengel and Barber (1974). Unlike RLD data, RWD were not significantly higher for no tillage under residue at the R1 growth stage.

Root Length to Weight Ratio

Root length to weight ratios, as an estimator of mean root diameter, ranged from 1 to 40 km/kg. At the V10 growth stage, mean root diameters decreased from no tillage to chisel plow to moldboard plow treatments in the 0 to 0.15 m layer next to the plant with no residue. Barber (1971) also noted coarser roots associated with no tillage, while Anderson (1987) noted no direct effect of tillage on root diameter. As roots developed from the V10 to R1 growth stage, length to weight ratios decreased with no observable differences between tillage treatments. Roots became progressively finer with distance from the plant, particularly in the interrow. Residues promoted coarser root systems for chisel and moldboard plow treatments, but had no effect on the no tillage treatment at the V10 growth stage. As plant roots developed, mean root diameters tended to increase in upper soil layers near the plant.

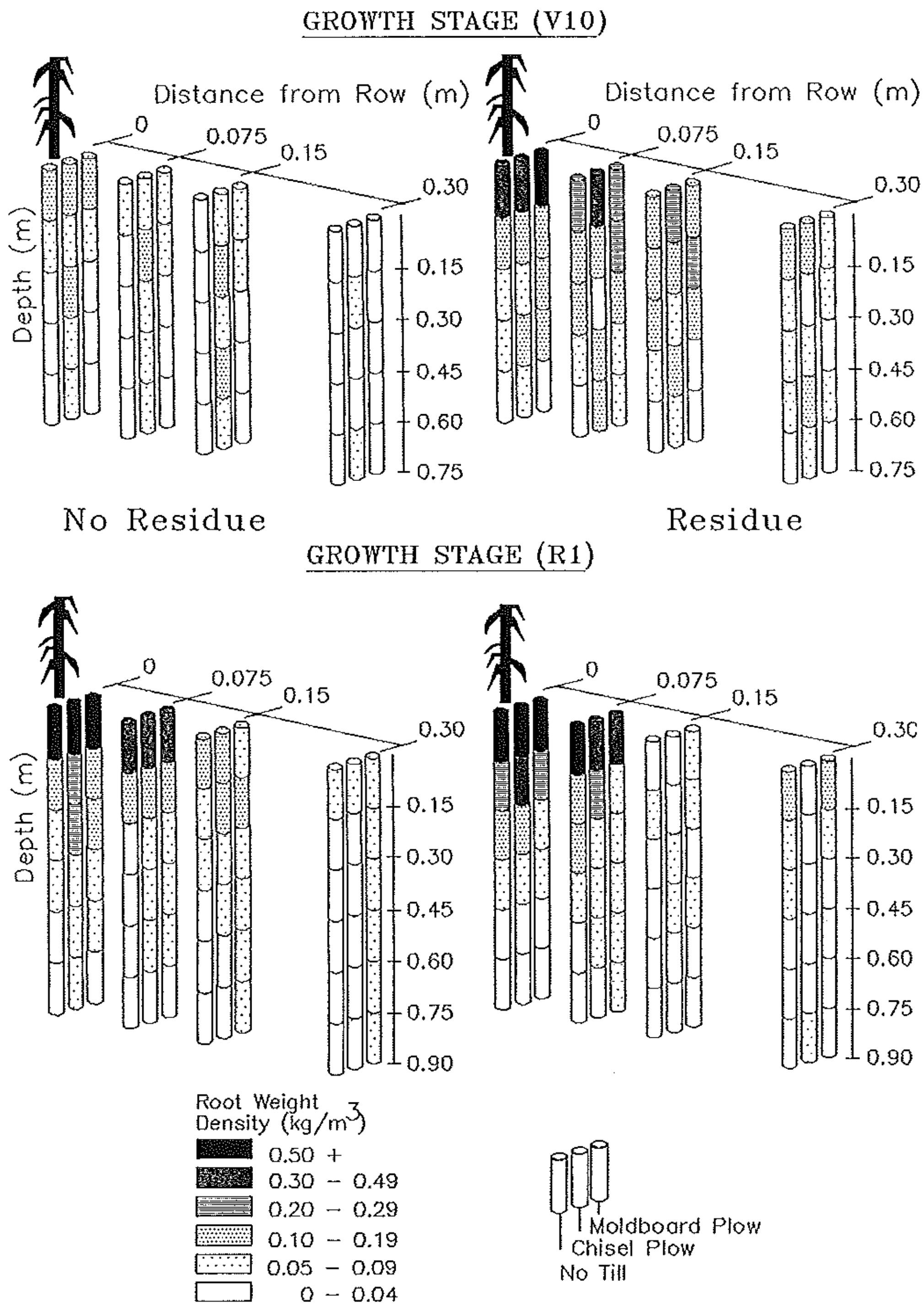

Fig. 2. Corn root weight density at two growth stages following 7 years of continuous cropping, tillage, and residue treatments.

However, root diameters at the R1 growth stage remained unchanged or decreased in the interrow and were comparable for all treatments.

CONCLUSIONS

Tillage, residues, and tillage x residue combinations did influence corn rooting patterns after 7 y of continuous corn.

1. Maximum RLD were associated with chisel plow treatment to depths of 0.75 m and up to 0.15 m from the plant in the absence of residue. Root length developed more slowly under no tillage and continued to increase to the R1 growth stage. Residue promoted RLD for no tillage and moldboard plow treatments for early (V10) growth. Residues concentrated root length development in the surface layer (0-0.3 m), particularly for the no tillage treatment. Below 0.15 m, lateral root distribution was not uniform among treatments.
2. Root mass increased by an order of magnitude between V10 and R1 growth stages, most notably in the 0-0.15 m layer. Residues stimulated early RWD increases. Below 0.15 m and beyond 0.075 m from the plant, roots died as fast or faster than new root mass was accumulating in the interrow area. By the R1 growth stage, no detectable differences in RWD existed between tillage treatments with residue present.
3. Mean root diameters decreased from no tillage > chisel plow > moldboard plow at the V10 growth stage with no residue. Residues promoted coarser roots for chisel and moldboard plow treatments only. By the R1 growth stage, length to weight ratios were the same for all tillage treatments in the presence of residue.

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INFLUENCE OF LONG-TERM NO-TILLAGE ON ROOTING IN AN ULTISOL

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ABSTRACT

Soil physical properties and crop rooting were examined after ten years of continuous no-tillage or conventional tillage production practices. Conventional tillage consisted of a moldboard plow/disk system. Bulk density and cone index measurements indicated the presence of a compacted zone from 0.10 to 0.20 m soil depth under no-tillage. There was no evidence of greater macroporosity with no-tillage judging from moisture characteristic and saturated hydraulic conductivity data. Infiltration rates were significantly greater under no-tillage compared to conventional tillage. Rooting by soybean (*Glycine max* L. Merr.) was observed on the surface of minirhizotron tubes with a color video camera. Results indicate that roots are not deterred by the high density zone, presumably as a result of development of stable macropores through the compacted layer which are undetectable with penetrometer and density measurements.

INTRODUCTION

The Ultisols predominantly found in Georgia are sandy in texture with poorly developed structure. Over the past few years, our work has shown that continuous no-tillage over at least a 3-year period often results in a greater bulk density and greater mechanical impedance in the soil surface (0 to 10 cm) compared to conventional tillage (NeSmith, *et al*, 1987a,b; Tollner *et al*, 1984). Due to the sandy texture, low organic matter content, and poor structural stability, the surface soil tends to compact under no-tillage. Furthermore, with shallow disk tillage, which is common in Georgia, "tillage pans" tend to form immediately below the depth of tillage. By restriction of root proliferation, these tillage pans can be more detrimental to crop yields than surface compaction due to no-tillage.

In areas of the U.S.A. with well-structured soils, the bulk density has tended to stay the same or even decrease with continuous no-tillage compared to conventional tillage (Blevins *et al*, 1983). The reason for less density with no-tillage is the formation and preservation of relatively large, continuous pores. Furthermore, it has been demonstrated that earthworm populations increase for no-tillage compared to conventional tillage, resulting in increased soil burrows and macroporosity (Edwards, 1975; Edwards and Lofty, 1980). Also, House and Parmelee (1985) demonstrated that soil arthropod and earthworm densities were greater for no-tillage compared to conventional tillage on an Ultisol in Georgia, but rooting was not measured in their study. It has been our observation that in long-term no-tillage plots (10 years) on a Cecil soil, crop performance has been good in years 5 through 10 even though dense compacted layers are present. It is our hypothesis that some large continuous pores through the compacted layers have been established and preserved through no-tillage management, which has allowed root proliferation into the subsoil.

Efforts to characterize the soil physical condition and, in particular, the pore size distribution, in these long-term studies have been made. In particular, measurements such as bulk density, mechanical impedance, water retention curves, and saturated hydraulic conductivity were made. Results tend to point to conventional tillage as a superior rooting environment due to less density, less mechanical resistance, and greater hydraulic conductivity. This is difficult to reconcile with our observation of greater plant growth with no-tillage. Greater soil water storage with no-tillage compared to conventional tillage has also been documented on these plots and may account for the greater plant growth. However, the influence of soil compaction on root growth and the distribution of roots may influence the plant accessibility to the additional water stored under no-tillage. Important parameters under consideration are: 1) The distribution of plant roots with depth under no-till and conventional tillage. 2) Tillage factors affecting root growth 3) Strategies for optimizing root distribution within a context of reduced tillage.

The objective of this study was to measure soybean (*Glycine max* L. Merr.) root growth in an on-going, long-term field experiment comparing no-tillage and conventional tillage practices. Quantification of root growth was used to document whether the measured physical parameters indeed impede root growth or perhaps the stable macropores were sufficient for root proliferation into the subsoil.

METHODS

The experimental site was a Cecil sandy loam (Typic Hapludult) located near Griffin, Ga. The soil physical condition had been recently characterized in terms of bulk density, penetration resistance, saturated hydraulic conductivity, and water retention. Details of the methodology and results of this characterization can be found in Radcliffe *et al* (1988).

Soybeans were grown in 1987 following wheat harvested for grain. Due to rainy, wet weather in June, the soybeans were not planted until June 30. Measurements of roots were made using a video camera/minirhizotron technique described by Upchurch and Ritchie (1983). Minirhizotron tubes were installed as described by Box and Johnson (1987) on July 15 and root counts were made on August 2, 19, 31, and September 20. Soybean top growth and soil water content were also measured on August 4, 20, 31, and September 9. Soybeans were harvested for seed yield determination on October 29.

RESULTS AND DISCUSSION

Briefly, results from the physical characterization of the soil can be summarized as follows. Cone index measurements indicated the presence of a compacted zone at a depth of 10 to 20 cm in the no-till treatment.

Also, bulk desity was significantly greater at this depth under no-tillge compared to conventional tillage (1.60 vs. 1.40 g/cm^3). However, water infiltration rates, measured with a sprinkler infiltrometer, were significantly greater with no-till compared to conventional till. The bare soil tended to crust thereby impeding the infiltration of water; whereas, the straw mulch and layer of fine, decomposed organic litter on the surface of the no-till soil prevented the formation of a crust. Removing the mulch and litter layer from the no-till soil sharply reduced the infiltration rate, while adding a mulch to the bare soil increased the infiltration rate. In fact, removing the mulch on the no-till soil resulted in an infiltration rate equal to that of the bare, tilled soil. It thus appears that infiltration in conventionally tilled soil is controlled by surface crusting and that the key to improved infiltration with no-till is the surface mulch and organic litter. A result of the improved water infiltration with no-till is that a greater portion of the spring and summer rainfall is captured and stored for plant use. However, the influence of soil compaction on root growth and the distribution of roots might influence the plant accessibility to the additional water stored under no-tillage. There is evidence that roots follow soil burrows and are thus able to exploit the soil profile more extensively (Edwards and Lofty, 1980).

Root counts per 10-cm depth increment are shown for four dates in Figs. 1-4. Initially root counts were not very different between conventional (CT) and no-tillage (NT) with the exception that conventional tillage appeared to have more roots between a depth of 20 and 30 cm (Fig. 1). By August 19 (about the time of flower initiation), the conventional tillage treatment had considerably more roots in the surface 40 cm of soil (Fig. 2). We surmise that this was a result of low mechanical impedance in the plowed soil and a relatively high soil moisture content which resulted from several small rainfall events during the first two weeks of August. However, by the next measurement (Aug. 31) and on all subsequent measurement dates, the no-tillage treatment had significantly more roots in the surface 30 cm of soil and tended to have more (but not statistically significant) at depths greater than 60 cm (Figs. 3 and 4). In fact, counts on Aug. 31 (Fig. 3) show a considerable decline for the conventional tillage treatment compared to 12 days earlier (Aug. 19, Fig. 2). We believe that root death occurred as a result of a period of about 4 weeks with no rainfall (Aug. 11 to September 5) in which the soil surface dried rapidly. However, soil moisture data (not shown) indicate that there was considerably more water stored under the no-tillage treatment. This apparently supported more root growth under the no-till treatment compared to the conventional treatment, but did not result in significant differences in top growth or N content (data not shown).

Perusal of crop yield data over the ten-year period of this experiment shows that for the summer crop, whether it be soybean or grain sorghum, no-tillage results in greater yields than moldboard plowed in years when significant moisture stress occurs (1979, 1981, 1983, 1985, 1986, 1987) and in equal yields in years when rainfall distribution is better (1982, 1984).

The reverse is true, however, for wheat. In years of high rainfall (1980, 1981, 1982, 1983, 1987) wheat yields were less with no-tillage compared to moldboard plowing, but in years with less than average rainfall in the winter and spring months (1984, 1985, 1986), yields were equal. The reason for less wheat yield with no-tillage is probably related to excessive soil moisture and reduced aeration with no-tillage in years of plentiful rainfall (Box, 1986).

Therefore, the greatest total production is achieved with fall tillage prior to planting wheat followed by no-till soybeans or grain sorghum. Since the fall is the period of least erosion hazard in Georgia (because of less total rainfall and less rainfall energy), tillage should be done at that time to maximize production in double-cropping systems. No-till production of summer crops should both protect the soil from erosion and result in more rainfall capture for crop use. These results should be applicable to similar Ultisols found in humid, temperate or subtropical environments.

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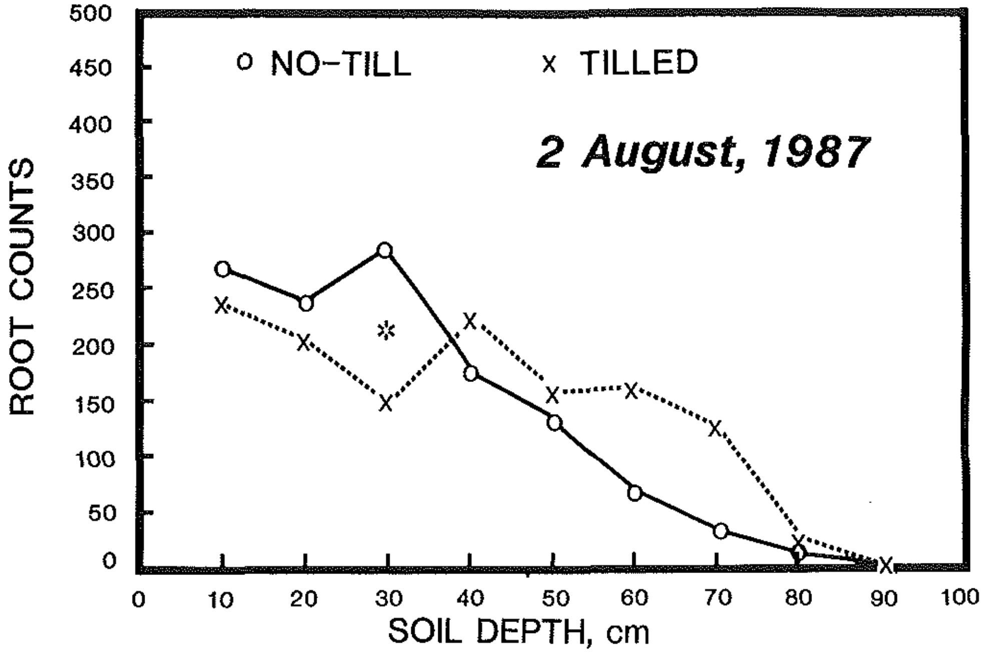

Fig. 1. Root counts as a function of soil depth on 2 August. (*) denotes a significant difference at the 95% confidence level.

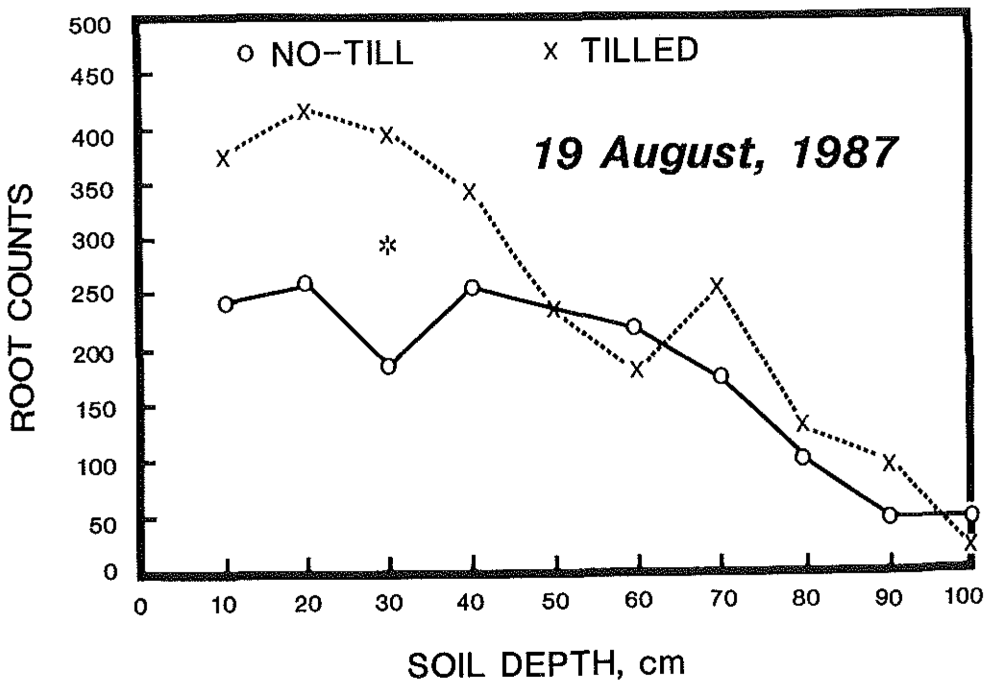

Fig. 2. Root counts as a function of soil depth on 19 August. (*) denotes a significant difference at the 95% confidence level.

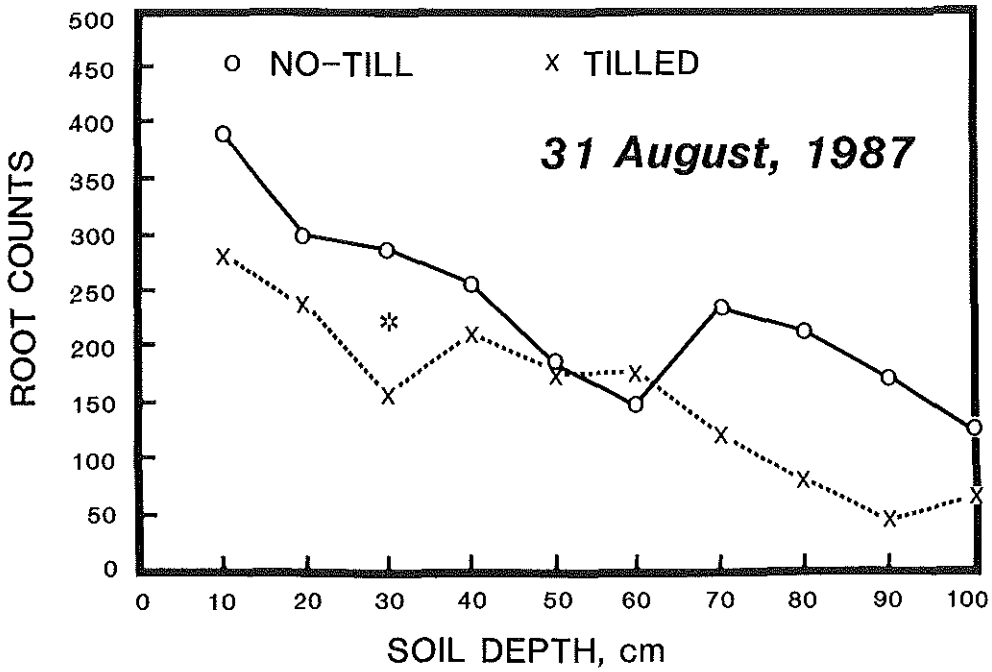

Fig. 3. Root counts as a function of soil depth on 31 August. (*) denotes a significant difference at the 95% confidence level.

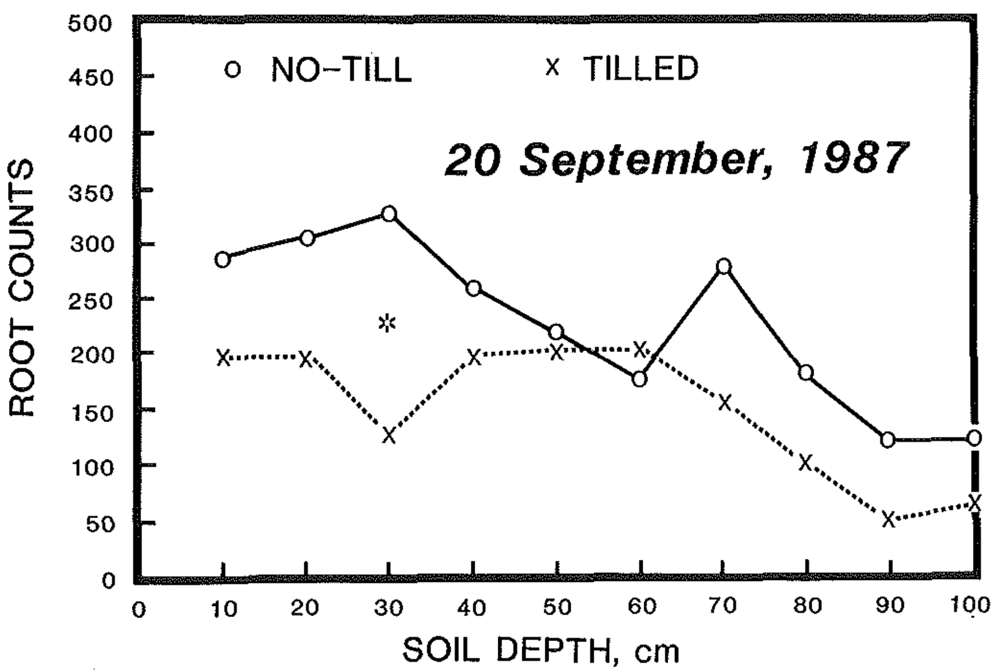

Fig. 4. Root counts as a function of soil depth on 20 September (*) denotes a significant difference at the 95% confidence level.

VERTICAL VERSUS HORIZONTAL TILLAGE: A MODEL STUDY

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ABSTRACT

The problem of oxygen movement to plant roots in a uniform soil with either vertical tillage (chiseling done perpendicularly to the surface of the soil) or horizontal tillage (chiseling done on the surface of the soil) was solved by the relaxation method (a numerical method). Theoretical results were compared with those obtained experimentally with an electrical analog. Theoretical and experimental results were similar. Flow of oxygen to the plant roots was 40 to 50% greater when tillage was vertical rather than horizontal. The results suggested that, since oxygen is necessary for active uptake of nutrients, fertilizer placed in bands (strips) perpendicular to the surface of the soil would be more readily taken up by plant roots than fertilizer placed in bands on the surface of the soil.

INTRODUCTION

Oxygen in the soil air is increased when the soil is tilled. Roots need at least 10% by volume air space in the soil to survive. The oxygen is used for metabolic processes, including active uptake of nutrients (Kirkham, 1987). Most studies of tillage and soil aeration have been qualitative and have not shown the precise connection between chisel openings and movement of oxygen in the soil to plant roots. The objective of the present experiment was to quantify the flow of oxygen in the soil to roots when chisel openings were oriented in either the vertical or horizontal direction.

MODEL

Figures 1 and 2 show the schematic model for the vertical-tillage and horizontal-tillage cases, respectively. Roots were assumed to be hanging vertically in sheets beneath rows of plants. The upper half of the root sheet was assumed to be inactive. Only the lower half of the root sheet was active and took up oxygen. This would be similar to a root system in the field where the upper, older portions of the system become inactive and the lower, younger portions of the system are active metabolically and take up oxygen and nutrients. The soil surface between plant rows was assumed to be sealed (closed to the movement of oxygen), except where the soil was tilled (chiseled). For the vertical-tillage case (Fig. 1), the soil was tilled vertically to a depth of 5 cm. The width of the chisel was assumed to be negligible compared to the depth of tillage. For the horizontal-tillage case (Fig. 2), the soil was tilled horizontally in a band of 5 cm on the surface of the soil. The depth of tillage vertically into the soil surface was assumed to be negligible compared to the width of tillage. A barrier (boundary) lay at the bottom of the model. The barrier could be clay, bedrock, a water table, compacted soil, or any barrier impervious to oxygen movement. Where the soil was tilled is where fertilizer could be placed. That is, it could be either knifed vertically into the soil (Fig. 1) or banded horizontally on the surface of the soil (Fig. 2).

Figures 1 and 2 show only one unit of the model. The rows of plants were assumed to be 20 cm apart. The 20-cm row spacing in the model fell within ranges of row widths used for wheat (*Triticum aestivum* L.) or soybean [*Glycine max* (L.) Merr.]. The model does not specify a crop. In the model, the physical situation from row to row repeated itself in units that could be added together to determine a cumulative effect.

The third dimension of the model (dimension 1 = distance between soil surface and barrier; dimension 2 = row width) was taken as a length perpendicular to the plane of the cross section of the model shown in Figs. 1 and 2. The third dimension was the length of the root sheet. The root sheets ran for infinity compared to dimensions 1 and 2. But, in theoretical expression, the length of the root sheet was considered to be a unit length.

Assumptions inherent in the model included the following: a homogeneous soil; oxygen diffusion in the gas phase; a uniform and limited root distribution; and steady-state flow. Steady-state flow is necessary because a Fick's-law analog is used in the study. Flow of oxygen in soil may be steady state for only short periods of time. Nevertheless, the steady-state assumption shows how the *geometry* of tillage affects oxygen movement to plant roots and can provide important conclusions about oxygen flow from the source (air at the surface of the soil) to the sink (active roots).

METHOD

A numerical method, usually known as the "relaxation method," was used to determine the flow of oxygen in the soil tilled vertically or horizontally. The numerical method is simple and a person with no mathematical training can work flow problems by using the method (Luthin and Gaskell, 1950; Kirkham and Powers, 1984). The relaxation method is as follows (Luthin and Gaskell, 1950). A square net or grid of uniformly spaced straight lines is drawn over a scale diagram of the region under consideration (ABCD in Figs. 1 and 2). Sides of the square of the net can be chosen so that the barrier passes through one side and a boundary of known potential passes through another side. After the net is drawn, known values of the potential are entered. In the present case, the potentials are the concentrations of oxygen in the soil. The known values are where the soil is tilled vertically or horizontally and where the active root surface is. The concentration of oxygen is arbitrarily taken to be 1.000 where the soil is tilled and it is taken to be 0.000 where the active root sheet is located. Estimated (guessed) values of the concentration are assigned at each interior point of the net. The interior points of the net are then traversed repeatedly, the values of concentration at each point being replaced by the average of its four neighbors (above, below, right, and left). If a value does not have a neighbor to the right (or left), the value to the left (or right) is taken as the value for the right (left) because the diagram ABCD is an image of the unit next to it. (Remember, only one unit of the model is shown in Figs. 1 and 2). Similarly, if a value has no value above (below), the value below it (above it) is taken for the missing value. An improved value of the concentration for each point is found each time that the net is traversed. Values obtained after traversing the interior points about five times change so little that the problem is regarded as solved, with precision limited by the coarseness of the net. In the present experiment, a net of squares of one inch (2.54 cm) on a side was used.

After the values of the concentrations were determined, values were interpolated to locate points for the 80, 60, 40, and 20 equipotentials (lines of equal concentration of oxygen). The chisel opening is the 100 equipotential; the active root sheet is the zero equipotential.

After lines of equal concentration were determined, the quantity of oxygen flowing per unit time, which left the chisel opening or entered the active root sheet, was calculated by using Fick's law of diffusion (Kirkham and Powers, 1984):

$$Q = DA(C_1 - C_2)/L \tag{1}$$

where Q (g/s) is the quantity of gas flowing through the soil per unit time, D (cm^2/s) is the diffusion coefficient, L (cm) is the length of the element (in the direction of the flow) through which the diffusion is occurring, A (cm^2) is the cross-sectional area of the element (taken perpendicular to the direction of the flow), and $(C_1 - C_2)/L$ is the concentration gradient, the units of $(C_1 - C_2)$ being g/cm^3.

To check the numerically determined values, the results were compared to those obtained with an electrical analog. The procedures and equipment used in the electrical analog have been previously described (Kirkham, 1987). The region ABCD of Figs. 1 and 2 was set up using the analog. The same dimensions were used in the analog as were used in the numerical problem (row width = 20 cm; chisel depth or width = 5 cm; active root sheet = 5 cm). Copper strips simulated the tilled strips (either vertically or horizontally oriented) and the active root sheet. Tap water stood to a depth of one inch (5 cm) in the container that held the two copper strips. The electrical-analog experiment was repeated three times so that a mean and standard deviation of the resistance values could be determined.

RESULTS

Figures 3 and 4 show the concentrations of oxygen at each point in the grid, determined by using the relaxation method, for the vertically-tilled and horizontally-tilled cases, respectively. Figures 3 and 4 also show the 0, 20, 40, 60, 80, and 100 equipotential lines (lines of equal concentration of oxygen) for the two cases. The lines crowd together where the source and sink are close together.

Values of Q, the quantity of oxygen that leaves the chisel opening or enters the active root sheet, were calculated by using the values in Figs. 3 and 4. For example, Q that leaves the chisel opening and moves into the soil to reach the root sheet in the vertically-tilled case, was determined as follows. Values in Fig. 3 are used. The average gradient, call it $(dC/dX)_{vsn}$, across the outflow (chisel) surface vsn is read from Fig. 3 as

$$\frac{dC}{dX}_{vsn} = \frac{(1.00-0.73) + (1.00-0.68) + (1.00 - 0.52)}{3} = 0.36$$

Let D be the diffusion coefficient in Fick's law. Then the flow Q_{vsn} from the "line" vsn is given by

$Q_{vsn} = D(dC/dX)_{vsn}A_{vsn} = D \times 0.36 \times 2$ (because $A_{vsn} = 2$) from Fig. 3). Or $Q_{vsn} = 0.72D$ per unit length of plant row.

There is flow going to the left from the chisel opening (Fig. 3). This flow Q_{mhe} is computed by using the same technique used to obtain Q_{vsn} and we get $(dC/dX)_{mhe} = 0.05$. So the flow Q_{mhe} from the line mhe is given by

$Q_{mhe} = D(dC/dX)_{mhe}A_{mhe} = D \times 0.05 \times 2 = 0.10D$ per unit length of plant row. And the total outflow per unit time Q_{chisel} is $Q_{chisel} = Q_{vsn} + Q_{mhe} = 0.72D + 0.10D = 0.82D$. This flow, 0.82D, enters one side (the left side) of the root sheet. We should get approximately the same value 0.82D for the flow $Q_{p_1h_1c_1}$ that goes into the root sheet at line $p_1h_1c_1$. We compute this latter Q by finding that $(dC/dX)_{p_1h_1c_1} = 0.42$. So the flow $Q_{p_1h_1c_1} = D \times 0.42 \times 2 = 0.84D$ per unit length of plant row, which compares with $Q_{chisel} = 0.82D$. These two values, 0.82D and 0.84D, are in better agreement than one might expect in view of the approximations that have been made in deriving the two values. The average of 0.82D and 0.84D is 0.83D, which we shall use in comparing results for the horizontally-tilled case.

Using procedures similar to those described above, we find for the horizontally-tilled case (Fig. 4) that $Q_{chisel} = Q_{def}$ = 0.57D per unit length of plant row. Oxygen flows from only one side of the chisel opening (the lower side). So we compute Q for only one side. $Q_{k_1e_1u}$ for the active roots = 0.53D per unit length of plant row. The values (0.57D and 0.53D) are in fairly good agreement. The average of 0.53D and 0.57D is 0.55D.

Results from the electrical analog were as follows:

Vertical tillage: 772±15 ohms
Hortizontal tillage: 1090±34 ohms

By Ohm's law we know that the flux (Q or current I) is inversely proportional to resistance or directly proportional to conductance [1/R = 1/ohm = mho = 1 Siemen (S)]. Taking the ratio of conductances as follows:

$$\frac{\text{Conductance vertical tillage}}{\text{Conductance horizontal tillage}} = \frac{0.00130\text{S}}{0.00092\text{S}} = 1.4$$

The ratio of the Q's for the horizontal and vertical tillage determined by using the relaxation method were as follows:

$$\frac{Q \text{ vertical}}{Q \text{ horizontal}} = \frac{0.83}{0.55} = 1.5$$

The ratios obtained with the numerical method (1.5) and with the electrical analog (1.4) were thus similar, a check.

CONCLUSION

Flow of oxygen into the soil to plant roots is greater by 40 to 50% if the soil is tilled vertically rather than horizontally. Therefore, banding of fertilizer in vertical strips perpendicular to the soil surface might permit more nutrient uptake if the fertilizer were placed in strips on the surface of the soil.

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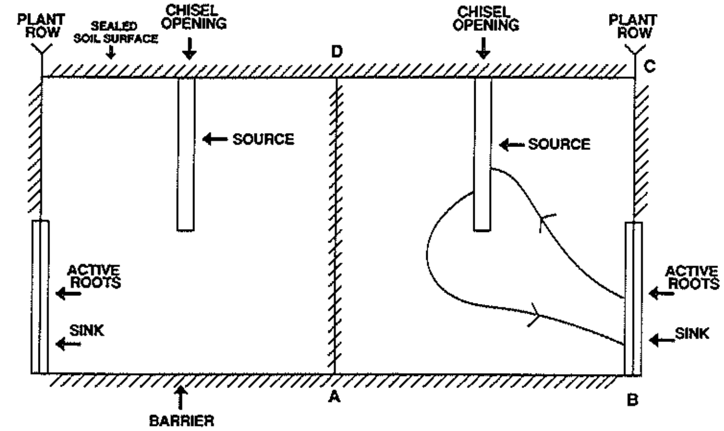

Fig. 1. Model of O_2 flow-vertical tillage.

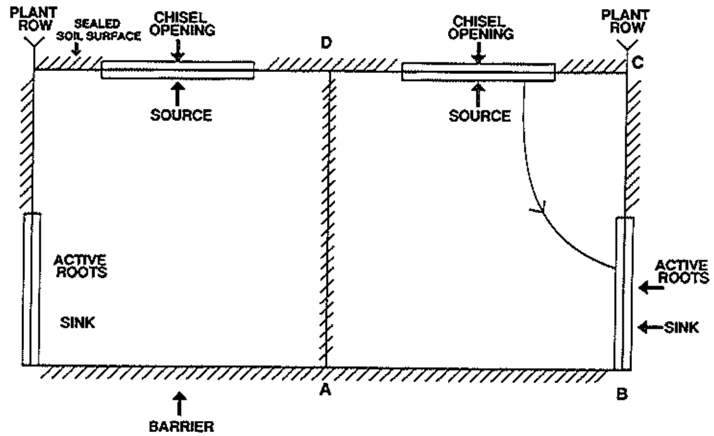

Fig. 2. Model of O_2 flow-horizontal tillage.

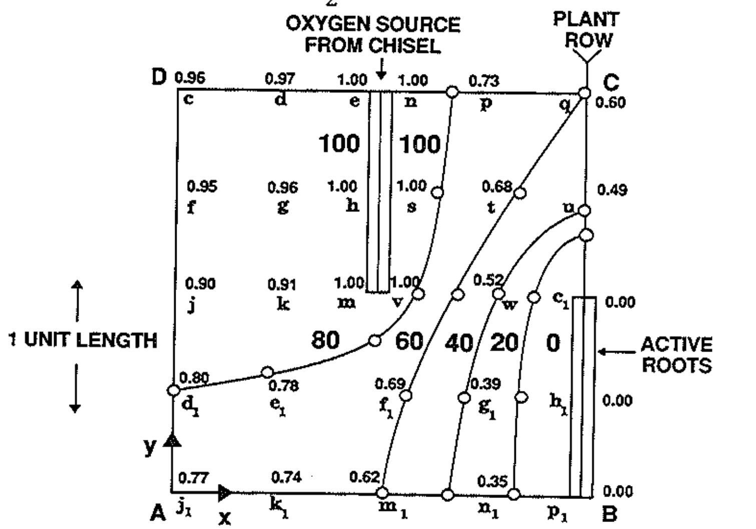

Fig. 3. Lines of equal O_2 conc.-vert. tillage.

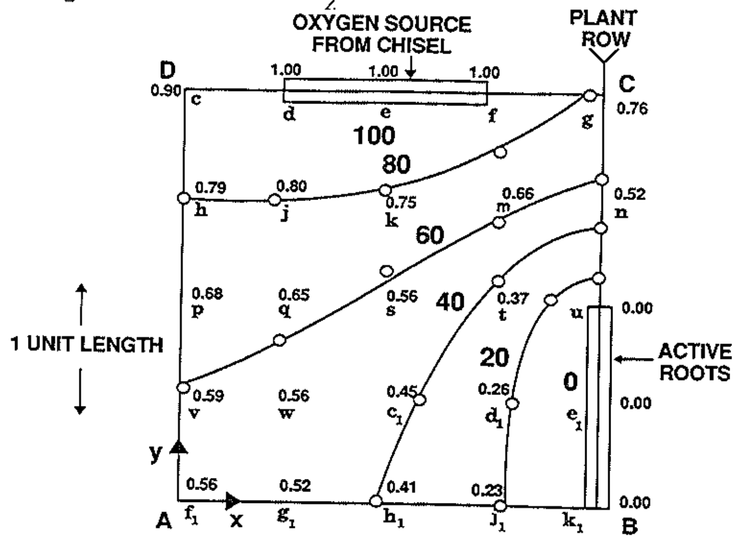

Fig. 4. Lines of equal O_2 conc.-hor. tillage.

SPATIAL DISTRIBUTION OF SOIL STRUCTURAL PROPERTIES UNDER CONSERVATION TILLAGE SYSTEMS

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ABSTRACT

Penetration resistance and other soil physical properties are being measured on three long-term conservation tillage sites in Indiana, USA. Measurements were made in three row positions (row, non-trafficked interrow, wheeltrack) on four tillage systems (moldboard plow, chisel, ridge, no-till) at each of the sites. As expected, penetration resistance in the surface 10 cm was generally lower for plow and chisel plots than for ridge and no-till, due to the loosening action of the tillage implements. On the two low organic matter Alfisols, no-till was generally less resistant than the other tillage systems in the 10-25 cm depth zone, suggesting an improvement in soil properties with the cessation of tillage. On the Mollisol, plow and chisel treatments were less resistant than no-till or ridge plots throughout the tilled layer.

INTRODUCTION

Conservation tillage systems affect many soil physical properties. The spatial distribution of these properties with row position and depth may also differ with tillage system and is important for quantitative tillage models (Cassel and Nelson, 1985). More data are needed on the spatial and temporal distribution of soil properties under different tillage systems and on different soils, in order to adequately model and predict crop response to tillage system.

Crop growth and yield and soil physical properties are being measured on three long-term conservation tillage studies in Indiana, USA (Kladivko *et al.*, 1986). Heard *et al.* (1988) sampled two of these studies and found that tillage system generally had a greater relative effect on soil air permeability of a poorly-structured Alfisol than of a well-structured Mollisol. Some improvment in soil structure was found on all conservation tillage systems in the study, as evidenced by increased air permeability. Row position tended to have a greater effect than tillage treatment on measured soil properties of the Mollisol, suggesting a decline in soil structure in the interrow of the tilled systems.

In this paper we report some of the results of penetration resistance measured on all three sites and bulk density and air permeability measured at one site, during the 1987 growing season.

MATERIALS AND METHODS

Measurements were made on three long-term conservation tillage sites. Pertinent soil characteristics are given in Table I. A detailed descripition of tillage and cultural practices for the Chalmers and Clermont sites is given by Heard *et al.* (1988). The Blount site had the same tillage treatments as the other two sites. Chiselling was performed in the autumn on all three sites, whereas moldboard plowing was done in the autumn on the Chalmers and Blount soils but in the spring on the Clermont soil.

Penetration resistance was measured with a constant-rate cone penetrometer, modified from the design of Lowery (1986). Two transects were made in each of the four blocks of the continuous corn (*Zea mays* L.) plots giving a total of 8 replicates for each of three row positions (row, non-trafficked interrow, wheeltrack) and four tillage systems at each site. Measurements were made in late May and early June, 1987, about 3-4 weeks after planting at each site. Soil water content was measured gravimetrically in conjunction with penetrometer measurements, but few differences existed among treatments at that time of the season and data are not presented here.

Intact soil cores (10 cm diameter, 8 cm height) were taken at the 5-13 cm depth on the four tillage systems at three row positions on the Blount site. Measurements of bulk density, water retention at 0, - 2, - 5 and - 10 kPa water potential, and air permeability (K_{air}) at - 10 kPa water potential were made on the core samples. Air permeability was measured and calculated as described by Heard *et al.* (1988).

Table I. Characteristics of three Indiana soils used in tillage studies.

Soil Series	Taxonomy	O.M.	Clay	Silt	Year[a]
		------------	%	----------	
Chalmers silty clay loam	Mollisol	4.0	32	59	1975
Clermont silt loam	Alfisol	1.3	10	73	1980
Blount silt loam	Alfisol	1.7	21	59	1984

[a]Year study began.

RESULTS AND DISCUSSION

In the interrow position of the well-structured Chalmers soil, ridge and no-till plots had similar cone index values and were more resistant than chisel and plow plots in the tilled zone (Fig. 1). Below the depth of primary tillage all four systems were similar. On the poorly-structured Clermont soil, the plow and chisel treatments were much less resistant than the ridge and no-till in the top 10 cm of the profile (Fig. 2). However, the no-till was less resistant than both the chisel and ridge plots below 16 cm depth. This suggests an improvement in soil structure with no-till on the Clermont and agrees with the air permeability evidence of Heard *et al.* (1988). The plow plots had very low resistance in the top 20-25 cm because measurements were made in the spring within 6 weeks of plowing, whereas chiselling had been performed in the autumn.

The moderately structured Blount soil again showed plow and chisel to be less resistant than ridge and no-till near the soil surface in the interrow position (Fig. 3). Below 10 cm the no-till was less resistant than the other three tillage systems, again suggesting an improvement in soil properties with no-till. Similar results were found in the row position (Fig. 4). Tillage system had a significant effect on bulk density, water drained between - 2 and - 5 kPa potential, and K_{air} measured on cores from the 5-13 cm depth. Bulk density (Mg m^{-3}, averaged over all three row positions) was lowest for plow (1.31) and highest for ridge (1.44) with chisel and no-till being intermediate (both 1.40). K_{air} values were in the order no-till > plow > chisel > ridge. Bulk density, cone resistance, and K_{air} data all reflected the denser and less permeable structure of the ridge system compared to the plow system on this soil.

In the wheeltrack (Fig. 5), the ridge and no-till plots had much greater resistance than plow and chisel, reflecting the permanent wheeltracks of ridge and no-till *vs.* only one pass of the wheel during planting of the plow and chisel plots. Wheeltrack effects were fairly shallow on this site, extending down only to 14 cm depth. Below 14 cm no-till was again less resistant than chisel and ridge.

In all four tillage systems, row position had a significant effect on most of the properties measured on the 5-13 cm depth soil cores. The wheeltrack had a higher bulk density, lower K_{air}, and lower water retention at - 2 kPa than the other row positions, which agreed with the greater measured cone resistance in the wheeltrack. Differences between the row and interrow positions as measured on the soil cores, were smaller and less consistent. The penetrometer measurements were more sensitive to these small differences and generally showed the interrow to be less resistant than the row.

CONCLUSIONS

The data suggest that no-till systems are more likely to decrease penetration resistance in the 10-25 cm depth zone, compared to other tillage systems, on soils that are initially poorly structured or low in organic matter. Some amelioration of previous tillage pans may be occurring after tillage practices cease. The ridge system appeared to increase penetration resistance and bulk density of the Blount soil, when compared to moldboard plowing.

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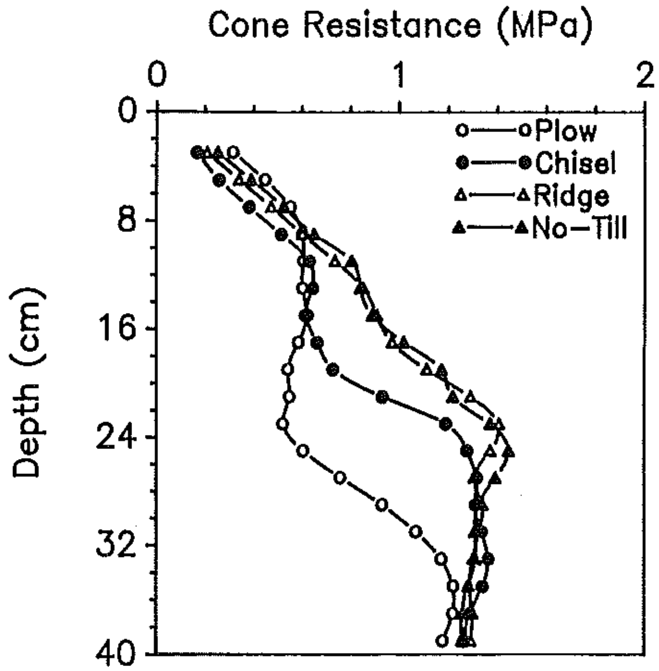

Fig. 1. Cone resistance at interrow position in four tillage systems on Chalmers soil.

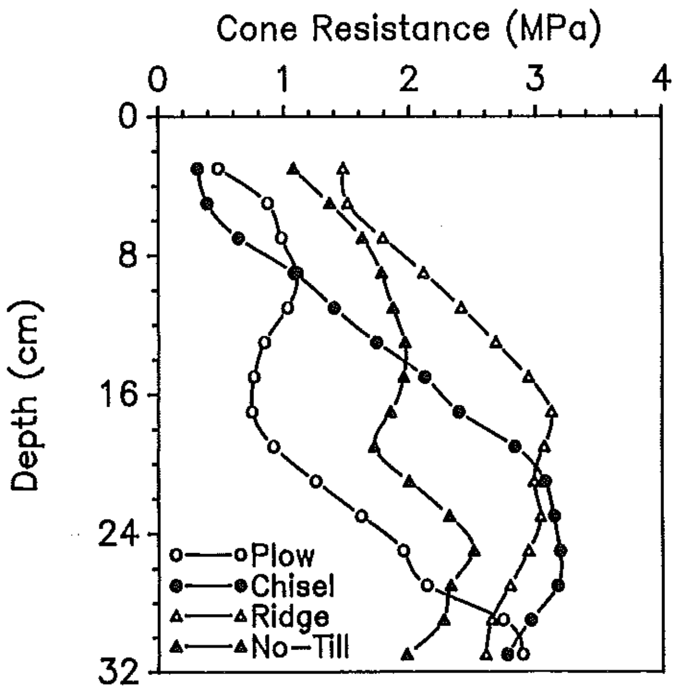

Fig. 2. Cone resistance at interrow position in four tillage systems on Clermont soil.

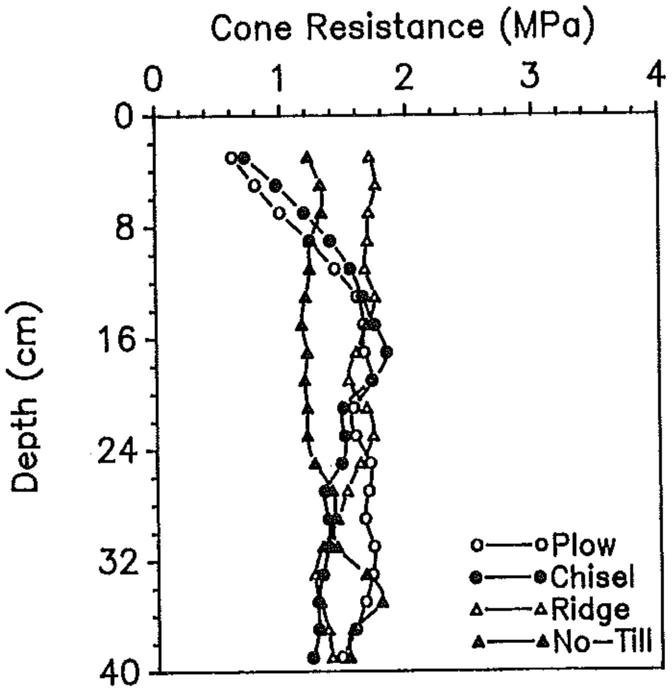

Fig. 3. Cone resistance at interrow position in four tillage systems on Blount soil.

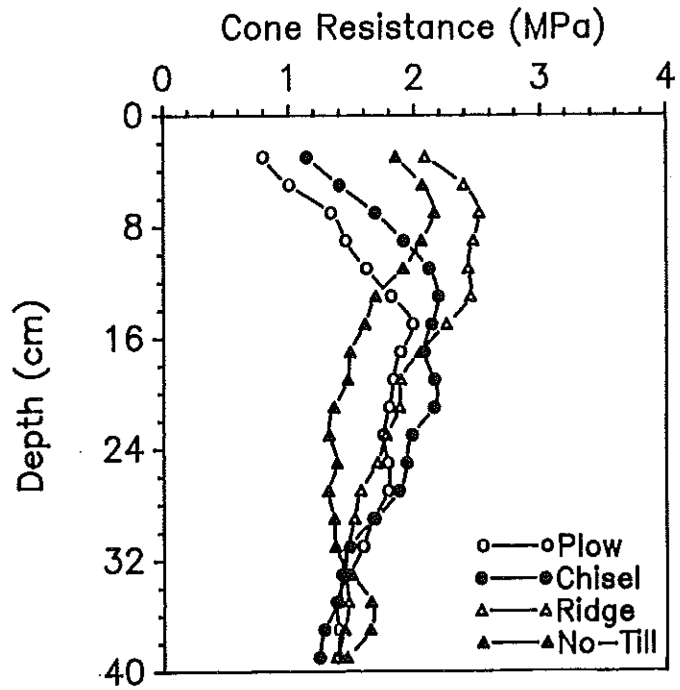

Fig. 4. Cone resistance at row position in four tillage systems on Blount soil.

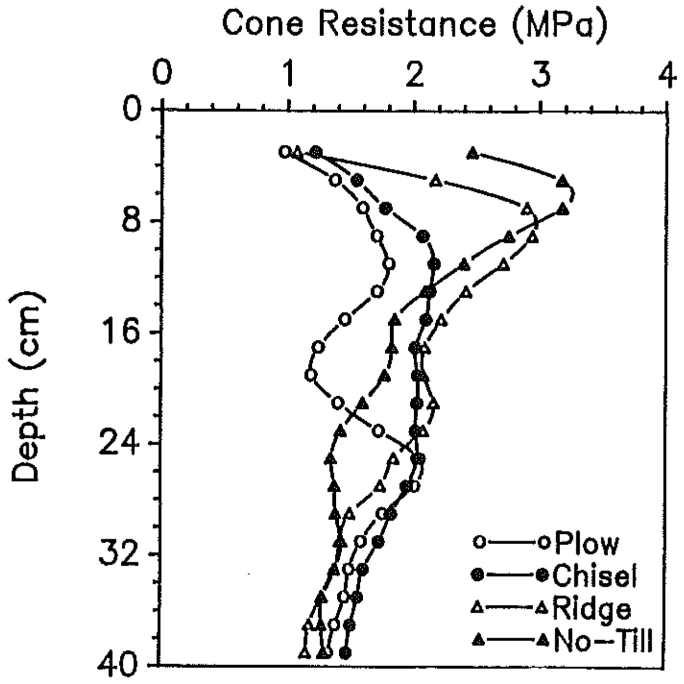

Fig. 5. Cone resistance at wheeltrack position in four tillage systems on Blount soil.

SOIL PHYSICAL FACTORS INFLUENCING SUGAR BEET EMERGENCE, ROOT SHAPE, AND ROOT YIELD ON A RANGE OF IRISH SOILS

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ABSTRACT

The influence of structural and textural properties of the Ap horizon on sugar beet seedling emergence, root shape and root yield are reported for 12 Irish tillage soils. Relationships of root shape and root yield with textural properties of the B horizon, and of root yield with textural properties of the C horizon are also discussed. Seedbed aggregate size was found to be the most important factor governing emergence. Root shape was mainly controlled by structural properties of the Ap horizon especially % organic matter and consistence limits. Textural properties of the B horizon (particularly sand content) were more important than those of the Ap and C horizons and structural properties of the Ap horizon with respect to root yield.

INTRODUCTION

An area of 35,000 ha of sugar beet (*Beta vulgaris* L.) is grown each year in Ireland which represents about 7 % of the total arable acreage. For reasons of climatic advantage the main growing areas are located in the southern coastal area and the southeast (Burke, 1968). These areas have a 10% advantage in season growth potential compared with the lower yielding midland areas. However, within the sugar beet growing area of southeast Ireland yield varies considerably with soil type (Lee and O'Connor, 1976). Highest yields are associated with friable, well aerated soils of adequate depth, classified as Acid Brown Earths and Brown Podsolics (Dystrochrepts and Haplorthods). Lowest yields are found mainly on Gleys and Grey Brown Podsolics (Umbraquepts and Glossudalfs) which are characterized by impeded or compacted subsoil, heavy texture or weak structure.

As with any crop, percentage seedling emergence is an important component of final sugar beet yield. Soil physical properties of the seedbed such as organic matter, soil moisture and aggregate size distribution influence emergence and hence establishment and yield (Hamblin and Davies, 1977; Sperlingsson, 1981). Root shape is also important in final yield. Forking or fanging of sugar beet taproots reduces potential yield. Also, more soil adheres to forked roots than to well-shaped ones at harvest thus increasing tare percentage and cleaning costs at the sugar processing factory. Additionally, root shape serves as a useful indicator of soil structural conditions, with severe forking denoting compaction (De Leenheer and Appelmans, 1973).

In order to further elucidate the soil physical reasons for sugar beet yield variation, in the light of decreasing crop rotational practices and increasing incidences of soil compaction, a series of soil management experiments was conducted in southeast Ireland over the three year period 1982-84. These studies investigated the effect of soil physical properties, autumn deep loosening, and spring seedbed cultivations on sugar beet growth and yield (Larney, 1985). The deep loosening aspects of this study have been reported (Larney and Fortune, 1986). The work outlined here examines the exact nature of the influence of soil textural and structural properties on (1) sugar beet seedling emergence; (2) root shape and (3) root yield. It is hoped that this information will help explain some of the soil physical factors causing sugar beet yield variation under Irish climatic and soil conditions.

MATERIALS AND METHODS

Four different sites were chosen in each of the three years 1982, 1983 and 1984 (Table I). Deep loosening and seedbed cultivation treatments were imposed on each site (Larney, 1985; Larney and Fortune, 1986). All 12 sites were located in southeast Ireland where the mean annual rainfall is about 800 mm and mean annual evapotranspiration is about 450 mm. Of the 12 sites, 8 were Grey Brown Podsolics (Orthic Hapludalfs) and 4 were Brown Earths (Orthic Dystrochrepts). They ranged in texture from sandy loam (Fenagh, Pump Field) to clay loam (Ashfield) and varied in structure from good (Ferns, Fenagh, Pump Field) to moderate (Ashfield, Hollymount Busherstown, Paulstown) to poor (Churchtown, Donabate, Athy, Oak Park, Maganey). Sites were planted to sugar beet in April of each year. More precise husbandry details are given by Larney (1985).

The following soil measurements were made for the Ap horizon of each of the 12 soils using conventional methods: particle size analysis; organic matter; water stable aggregates; moisture content (MC) at 6 kPa tension (field capacity); liquid and plastic limit moisture content. Particle size fractions were as follows: coarse sand (2-0.2 mm); fine sand (0.2-0.05 mm); silt (0.05-0.002 mm) and clay (< 0.002 mm). The plasticity index and the ratios of fine sand to coarse sand (FS/CS), and of plastic limit to field capacity (PL/FC) were calculated. Particle size analysis was also carried out on the B and C horizons of all 12 soils. Additionally site averages (averages of all cultivation treatments) of seedbed aggregate size distribution were obtained by dry sieving. These included mean weight diameter (MWD, Youker and McGuinness, 1957), cloddiness ratio (% aggregates > 9.4 mm divided by % aggregates < 9.4 mm) and % aggregates < 4.8 mm. Values of all these properties for the 12 sites are given by Larney (1985).

The following crop measurements were taken on all plots at each site: (a) % emergence (calculated from the number of plants counted at the four leaf stage expressed as a % of the total number of plants in an equivalent row length assuming 100% establishment), (b) % well-shaped roots (separated visually from slightly forked and severely forked roots at harvest and expressed as a % of the total number of roots per plot), (c) root yield. Site averages of these three crop measurements were calculated from plot values. Table I shows crop performance values for each of the 12 sites.

RESULTS

Factors influencing seedling emergence

Sugar beet seedling emergence values were correlated with 8 selected soil structural properties (% organic matter, % water stable aggregates, moisture content at 6 kPa tension, liquid limit, plastic limit, plasticity index, PL/FC ratio, moisture content at seedbed preparation) and 5 textural properties (% coarse sand, % fine sand, % silt, % clay, FS/CS ratio) of the Ap horizon (Table II). Emergence values were also correlated with 3 measurements of seedbed aggregate size distribution (mean weight diameter, % aggregates < 4.8 mm,

Table I. The 12 study sites and their crop performance data.

Year	Site	Emergence %	Well-Shaped Roots %	Root Yield t ha $^{-1}$
1982	Ashfield	68.0	83.6	26.9
	Churchtown	62.8	68.7	36.7
	Donabate	63.4	74.2	47.1
	Ferns	72.1	81.3	51.1
1983	Hollymount	74.4	73.3	53.2
	Athy	84.6	78.8	47.5
	Malones Field	71.5	71.1	37.2
	Fenagh	74.5	84.1	60.1
1984	Busherstown	69.2	66.0	57.1
	Paulstown	72.1	76.3	51.2
	Maganey	64.0	64.9	44.7
	Pump Field	80.8	82.4	44.2

Table II. Correlation coefficients (r) of % seedling emergence, root shape (n = 12), and root yield (n = 10) with structural, textural and seedbed aggregate size parameters of study soils. (Abbreviations explained in text). N.D., Not Determined.

Parameter	% Emergence	% Well-Shaped Roots	Root Yield
Ap Horizon			
% Organic Matter	0.35	0.84***	0.58*
% Water Stable Aggs.	0.04	0.67**	0.36
MC at 6 kPa	0.09	0.58*	0.17
Liquid Limit	0.08	0.76**	0.47
Plastic Limit	0.06	0.71**	0.46
Plasticity Index	0.10	0.74**	0.44
PL/FC Ratio	0.23	0.53*	0.56*
MC at Cultivation	0.25	0.66**	0.48
% Coarse Sand	0.31	0.34	0.75**
% Fine Sand	0.17	- 0.43	- 0.41
% Silt	- 0.21	- 0.07	- 0.43
% Clay	- 0.34	0.04	- 0.57*
FS/CS Ratio	- 0.13	- 0.42	- 0.73**
MWD	- 0.69**	- 0.30	- 0.74**
Cloddiness Ratio	- 0.58*	- 0.36	- 0.80**
% Aggs. < 4.8 mm	0.46	- 0.24	0.83**
B Horizon			
% Coarse Sand	N.D.	0.47	0.82**
% Fine Sand	N.D.	- 0.12	0.63*
% Silt	N.D.	- 0.29	- 0.74**
% Clay	N.D.	- 0.36	- 0.84**
FS/CS Ratio	N.D.	- 0.52*	- 0.66*
C Horizon			
% Coarse Sand	N.D.	N.D.	0.73*
% Fine Sand	N.D.	N.D.	0.19
% Silt	N.D.	N.D.	- 0.77**
% Clay	N.D.	N.D.	- 0.52
FS/CS Ratio	N.D.	N.D.	- 0.67*

*, **, ***: Significant at 5 %, 1 % and 0.1 % levels, respectively.

cloddiness ratio). Emergence did not show significant r values with any of the 7 structural properties, the strongest relationship being with % organic matter (0.35). Relationships with textural properties were also non-significant, the best being with % clay (r = 0.34). The strongest correlations were found between emergence and seedbed aggregate size parameters with r values of - 0.69**, - 0.58* and 0.46 for MWD, cloddiness ratio and % aggregates < 4.8 mm, respectively. Fig. 1 illustrates the significant linear relationship of seedling emergence with seedbed aggregate MWD.

Factors influencing root shape.

All 8 soil structural properties were significantly correlated with % well-shaped roots (Table II). The strongest relationship was with % organic matter (r = 0.84***), which showed that the higher organic matter soils resulted in less root forking (Fig. 2). Strong positive relationships were also present with liquid limit (r = 0.76**), plastic limit (r = 0.71**), % water stable aggregates (r = 0.67**) and moisture content at seedbed cultivation (r = 0.66**). The only soil textural parameter to show a significant correlation with root shape was B horizon FS/CS ratio (r = - 0.52*). In the A horizon the fine sand fraction exerted the largest effect on root shape (r = - 0.43) but this was non-significant. Total sand, silt and clay content of the A horizon had extremely weak effects on root shape as denoted by r values of 0.01, - 0.07 and 0.04, respectively. B horizon coarse sand content had a positive relationship with % well-shaped roots (r = 0.47) while that with B horizon clay content was negative (r = - 0.36).

Factors influencing root yield

Correlations for root yield are based on data from 10 sites as it was decided to omit the Ashfield and Pump Field data. Weed infestation and severe drought interfered with yield potential at these two sites, respectively. Root yield was positively correlated with all 8 of the Ap horizon structural properties, being significant with two of them: % organic matter (r = 0.58*) and PL/FC ratio (r = 0.56*) [Table II]. With respect to Ap textural properties root yield showed significant correlation coefficients with % coarse sand (r = 0.75**), % clay (r = - 0.57*) and FS/CS sand ratio (r = - 0.73**). Textural properties of the B horizon exerted the greatest influence on root yield with r values of 0.82**, 0.63*, - 0.74**, - 0.84** and - 0.66* for % coarse sand, % fine sand, % silt, % clay and FS/CS ratio, respectively. The negative relationship with % clay is shown in Fig. 3. In the C horizon the silt (r = - 0.77**) and coarse sand (r = 0.73**) fractions showed the strongest relationships with root yield.

DISCUSSION

Seedbed aggregate size distribution was more important than either structural or textural properties of the Ap horizon with respect to seedling emergence. As MWD and cloddiness ratio of the seedbed increased or % aggregates < 4.8 mm decreased (i.e. as seedbed coarseness increased, an indicator of poor soil structure) then % emergence decreased.

The significant positive correlations between % well-shaped roots and % organic matter, % water stable aggregates, moisture content at 6 kPa, liquid limit, plastic limit, plasticity index, PL/FC ratio and moisture content at seedbed cultivation indicate that good soil structural conditions are necessary for a high proportion of well-shaped roots.The relationship with the latter parameter (r = 0.66**) showed that as soil moisture content at seedbed cultivation increased then the % of well-shaped roots also increased. This indicates that adequate soil moisture must be

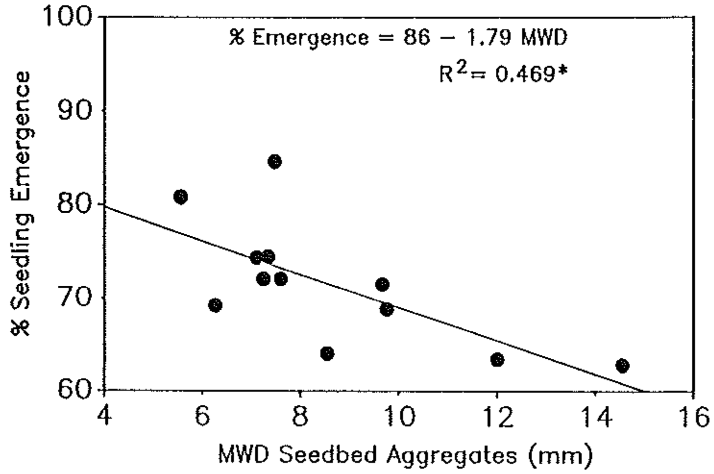

Fig. 1. Relationship between seedling emergence and seedbed aggregate size.

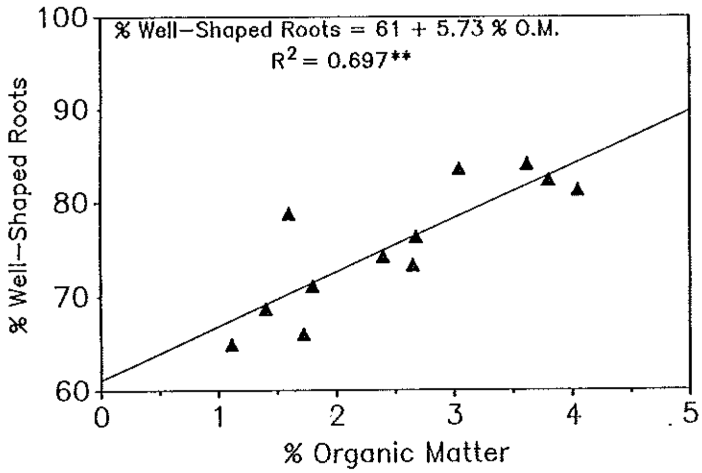

Fig. 2. Relationship between root shape and Ap horizon organic matter content.

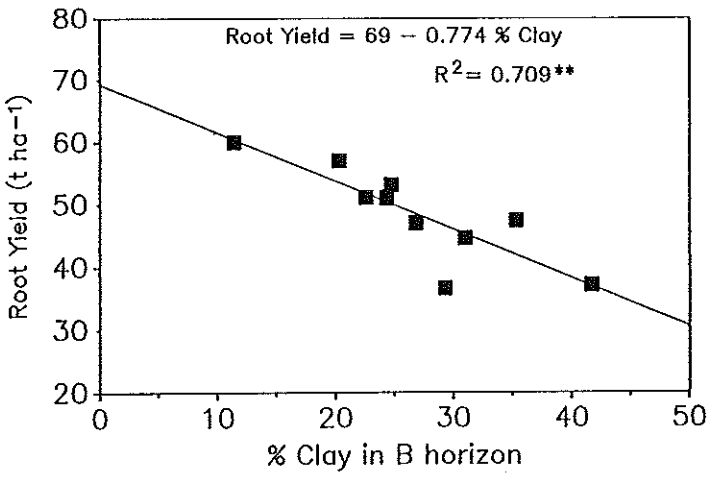

Fig. 3. Relationship between root yield and B horizon clay content.

present in the topsoil to allow fracturing and shattering of clods with the minimum number of cultivation passes. This in turn causes less soil compaction and encourages an increase in numbers of well-shaped roots.

Root yield had significant negative correlation cofficients with both % clay (- 0.57*) and FS/CS ratio (- 0.73**) of the Ap horizon. As both these parameters increased then root yield decreased, indicating that optimum yields occurred in soils of low clay content with equal amounts of fine and coarse sand. Root yield was also significantly influenced by organic matter content of the topsoil (r = 0.58*). Textural properties of the B horizon were more important than those of the Ap and C horizons with all particle size fractions having significant effects on root yield. High sand and low clay contents in the B horizon resulted in the highest yields. High FS/CS ratios (an indicator of soil compactability) led to decreased yields as denoted by the negative relationship (r = - 0.66*). On the average textural properties of the C horizon had a larger effect on root yield than those of the Ap horizon, the silt fraction being the most dominant. Taking all three horizons together the coarse sand fraction exerted the most influence on root yield with an average r value of 0.77.

CONCLUSIONS

(1) Seedling emergence was influenced mainly by seedbed aggregate size distribution. No significant relationships were found between emergence and structural or textural properties of the Ap horizon.

(2) Root shape was highly correlated with structural properties of the Ap horizon with well structured soils leading to reduced forking. Textural properties of the Ap and B horizons had little or no influence on root shape.

(3) Root yield was mainly governed by textural properties of the B horizon, followed by those of the C and Ap horizons. The sand fraction was the most influential. Percentage organic matter was the only structural parameter of the Ap horizon to significantly influence yield.

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HARD-SETTING BEHAVIOUR OF SOME STRUCTURALLY WEAK TROPICAL SOILS

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ABSTRACT

Some soils set hard on drying and may limit crop productivity. The hard-setting behaviour is influenced by soil properties and management. The aim of this study was to relate physical properties of sois sampled from three sites in Nigeria to soil strength or degree of hard-setting and to management. Clearing the vegetation and tillage decreased organic matter and wet aggregate stability and increased bulk density leading to an increase in soil strength. The soil strength increased as the water content decreased but the increase was much more marked for mechanized cleared or tilled soils than for the less disturbed treatments of forestry and a no-till system.

INTRODUCTION

Many tropical soils, which are often predominantly sandy in surface texture, become structurally unstable soon after they are cleared and brought under cultivation. The major causes of this instability are associated with the reduction of soil organic matter content, raindrop impact and decline in biotic activity of macrofauna (Tisdall and Oades, 1982). On fast wetting such soils slake and they are likely to set hard on drying. In Australia, this is referred to as hard-setting behaviour and Mullins *et al*. (1987) have proposed a physical explanation to describe it.

Because the deterioration of the physical properties of hard-setting soils is usually the factor which renders cropping marginal or uneconomic, there is an urgent need to identify and characterize those soil properties whose change results in a reduction in crop growth and yield. This study concentrated on both strength and structural instability because it is the combination of these two factors which leads to agronomic problems. Our strategy was to compare between 2 contrasting treatments, one of which was expected to have lead to greater soil degradation, on 3 sites in Nigeria. This work is described in more detail in (Ley *et al*., 1988a).

MATERIALS AND METHODS

Soils were sampled from paired treatments from 3 sites specifically chosen to span a range of climatic regimes and soil physical properties (Table I). At Samaru the treatments were part of a long-term experiment involving continuous maize cropping from 1978 to 1985 and consisted of a no-till (NT) and disc harrowed (T) treatment (Ike, 1986), sampled after harvest. At Mokwa one treatment (F), consisted of a forest plantation of *Gmelina arborea* planted in 1972 and the other (T), was an area which had been cleared for farming in 1979 and had been taken out of a 3 year grass fallow by disc harrowing 4 weeks prior to sampling. At the International Institute for Tropical Agriculture (IITA), one treatment (FC), was manually cleared from rainforest directly prior to sampling and the other (MT), had been cleared with a treepusher/root rake in 1979 and subsequently ploughed (Couper *et al.*, 1981). The soil surface had been scraped off during clearing and in the 3 years prior to sampling (after harvest) the latter treatment had been direct drilled with maize and cowpeas.

Undisturbed soil minicores (22 mm ID, 40 mm long) were sampled with a specially designed thin walled sampler from 40 to 80 mm depth and were transported in pvc split cylinder sample holders. Bulk samples were also obtained from the same depth. Minicores were slowly wetted to saturation and sets of 10 cores were each equilibrated at matric potentials of -3, -100, -300 and -1000 kPa, whilst one set was allowed to air-dry (AD). The unconfined compressive strength and moisture contents of the equilibrated cores was measured as described by Mullins and Panayiotopoulos (1984). Calipers were used to determine the volume of equilibrated cores and hence their dry bulk density.

Bulk soil samples were broken into large aggregates prior to determination of their water stability using the Yoder wet sieving method. Water suspendable solids (wss) was determined on duplicate 10 g subsamples of air-dry soil dialysed for 4 days until the conductivity of the soil solution was <5 µS/cm. The dialysed suspension was transferred to a 500 ml cylinder, made up to the mark with distilled water, stirred with a plunger and the concentration of suspended solids <50 and <2 µm determined using a pipette.

RESULTS AND DISCUSSION

Table I gives a summary of the soil physical properties. Paired treatments at Samaru and IITA had sufficiently similar particle size distributions to make a meaningful comparison between treatments. Because this was not true for the Mokwa treatments, any comparisons between treatments refer only to Samaru and IITA sites.

Table I. Location, soil type and physical properties of no-till (NT), tilled (T), forest (F), freshly cleared (FC) and mechanically cleared and tilled (MT) treatments. Bulk densities are for minicores equilibrated at -100 kPa. Water stable aggregates is (wsa), mean weight diameter (mwd), and water suspendable solids (wss). Coefficients are for the equation

Strength = a m^b for -1MPa < matric potential < -3 kPa where m is soil moisture content (g/g).

	Site					
	Samaru		Mokwa		IITA	
Location	11° 11'N,7°38'E		9°18'N,5°4'E		7°30'N,3°54'E	
Soil	Typic Haplustult		Ferralitic/ Ferrisol		Oxic Paleustalf	
Treatment	NT	T	F	T	FC	MT
Particle size (%)						
2000-50 μm	51	55	76	66	59	64
50-2 μm	39	34	18	24	18	12
<2 μm	10	11	6	10	23	24
Organic C (%)	1.2	0.6	0.6	0.3	1.6	1.4
Bulk density (Mg/m^3)	1.40	1.50	1.41	1.63	1.18	1.53
wsa (%)						
4-11 mm	93	15	94	45	87	56
<0.125 mm	5.6	56	1.5	34	4.2	16
mwd (mm)	7.0	1.4	6.2	3.1	5.8	4.0
wss (%)						
<50 μm	37	47	17.9	33	22	23
<2 μm	3.2	2.5	1.9	3.5	5.1	7.6
AD strength (kN/m^2)	309	354	156	732	182	855
s.e.	44	22	18	43	28	71
Strength equation coefficients						
a	746	1088	233	2542	2.3×10^5	1.9×10^6
b	-1.096	-1.141	-0.86	-1.515	-2.917	-3.629
r (all ***)	-0.95	-0.90	-0.92	-0.90	-0.73	-0.86

Minicore bulk densities did not show any significant increase with progressive drying from -3 kPa to AD although AD values were consistently higher than those at other potentials. This indicates that the sampling technique provided reproducible samples and that there was hardly any sample shrinkage on drying. The low bulk density of the FC treatment at IITA is attributable to the vigorous earthworm activity as indicated by numerous worm casts. Although samples did not contain visible worm channels, the overall effect of their activity will have been to reduce the bulk density.

Water stable aggregate (wsa) results showed large and significant differences between treatments whereas the water suspendable solids (wss) did not reveal significant treatment differences. These results are consistent with the interpretation of structural binding presented by Tisdall and Oades (1982). They concluded that macroaggregates (>250 μm) are stabilized by roots and fungal hyphae so that, because soil management exerts a large influence on this type of binding, the results of tests on macroaggregates (e.g. the wsa test) are very sensitive to soil management. On the other hand, they invoked other types of binding agents (plant, fungal and microbial debris) which are much more persistent and less affected by changes in soil management to explain the binding in aggregates <250 μm in size. The wss provide an indication of the amount of silt and clay that can be mobilised during wetting and it is interesting to note that between 1/3 to 1/4 of the total clay was water suspendable and that, for the tilled treatments at Samaru and Mokwa all of the silt + clay was water suspendable.

Strength increased with decreasing moisture content and significant linear relationships were obtained between log strength and log moisture content for samples equilibrated at potentials between -3 and -1000 kPa (Table I). Correlations were sought between the strength of samples at each potential and all of the other variables listed in Table I but only the positive correlations between strength (at -3 kPa, -1 MPa and AD) and bulk density were found to be significant ($P<0.05$). An increase of strength with bulk density is to be expected and the lack of significance in other relations may only reflect on the small size of the data set.

On all of the 6 plots the greatest increase in strength occurred at potentials of less than -100 kPa, consistent with the suggestion that matric potential (i.e. effective stress) can make a major contribution to the strength of drying soil (Mullins et al., 1987) since, in the absence of shrinkage the contribution of chemical bonding to soil strength is unlikely to increase with the comparatively small decrease in moisture content which occurred between potentials of -100 kPa and -1 MPa (Fig.1). Indeed it has been possible to show that effective stress can account for over half of the strength of these samples at -100 kPa and can more than account for the strength of samples at -1 MPa (Ley et al., 1988b).

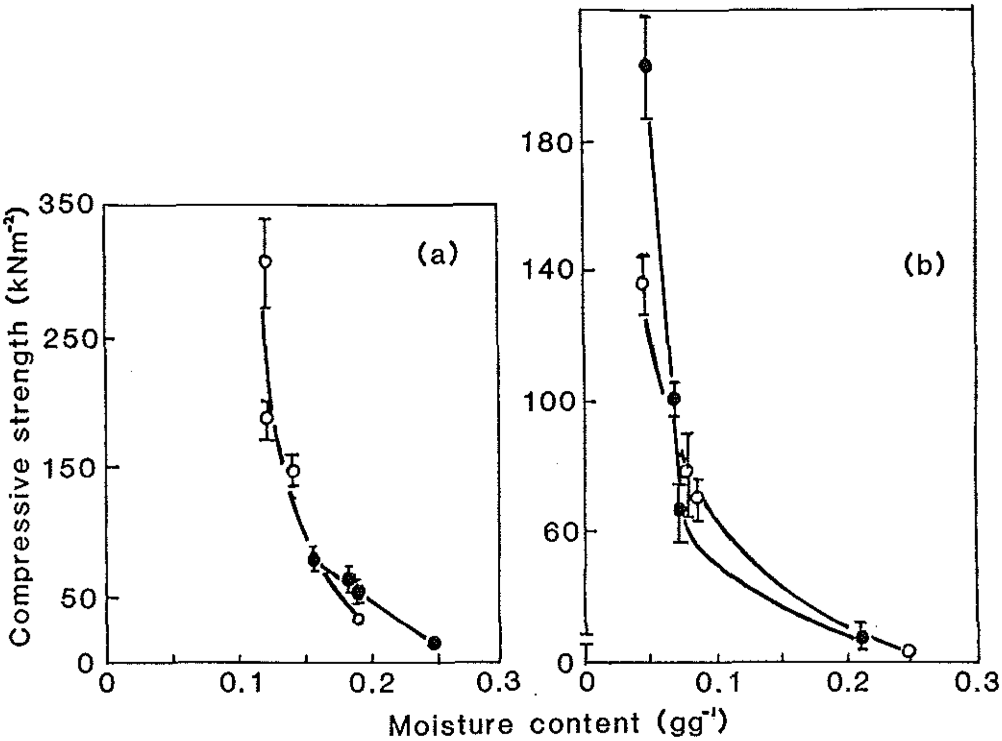

Fig. 1. Unconfined compressive strength versus moisture content of undisturbed cores at matric potentials of: -1000, -300, -100 and -3 kPa. (a) IITA site, open symbols (MT), solid symbols (FC); (b) Samaru site, open symbols (NT), solid symbols (T) treatment.

Strength results for two of the sites have been plotted in Fig.1 and show that the increase in strength with decrease in moisture content was more pronounced on the more disturbed treatments (T and MT) in comparison with their less disturbed counterparts. In soils like these which may not crack into structural units on drying, high values of soil strength can be deleterious both because they limit the times at which it is possible to cultivate or plant seeds, and because they restrict the rate and amount of crop root growth. Both of these limitations were apparent on the worse site at IITA. In comparison with the freshly cleared plot, it was not possible to plant seeds with a jab planter or tractor drawn seed drill into the MT treatment until a month after the better treatment had been sown and maize root growth was severely restricted in the worse plot.

CONCLUSIONS

(1) Compressive strength of undisturbed soil minicores increased as the soil moisture content decreased but the increase was more marked for soil which had been cleared with a treepusher/root rake and/or tilled in comparison with less disturbed treatments.

(2) This change in strength can increase restrictions on both the timing of cultivations or planting, and on the rate of root growth.

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A GEOSTATISTICAL ANALYSIS OF THE PENETROMETER SOIL STRENGTH OF A DEEP PLOUGHED SOIL.

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ABSTRACT.

The penetrometer soil strength (PSS) in a 1 ha vineyard on a red sandy clay loam, which four years previously had been double ploughed to a depth of 850 mm, was studied. A total of 172 measurements of PSS were made on a rectangular grid in which the smallest sampling interval was 1 m and the rest in multiples of 5 m. A geostatistical analysis of four depths using detrended residuals showed that PSS is spatially structured with an average range of influence of approximately 9 m. The definition of the spatial structure declined with depth and anisotropy was present in the 350 mm depth layer.

INTRODUCTION.

For many years it was generally accepted that the physical and chemical properties of soils can best be presented by the mean and variance of a sufficiently large sample size taken from that soil. This classical statistical approach assumes that variability of the particular property about the mean is random and contains no reference to the spatial distribution of differences within sampling units (Trangmar et al, 1985). During the last decade however, soil scientists have shown an increasing interest in studying the spatial variation and structure of soil properties. The more recently conducted studies on spatial variability were largely based on the theory of geostatistics (Journel and Huijbregts, 1978). This theory takes into account both structured and random characteristics of spatially distributed variables to provide quantitative tools for their description and optimal unbiased estimation. Infiltration rate (Vieira et al, 1981), soil temperature (Davidoff et al, 1986), and soil water pressure potential (Hamlett et al, 1986) are some of the properties that were found to be spatially dependent.

Penetrometer soil strength (PSS) is often used to evaluate the effectiveness of tillage practices. A question that arises is to what extent measurements of PSS might still be spatially structured following deep ploughing. The aim of this study therefore, was to use geostatics to analyse the spatial structure of penetrometer soil strength.

METHODS AND MATERIALS.

The penetrometer soil strength (PSS) of a 1 ha vineyard on a red sandy clay loam was studied. Before establishing the vineyard, and four years prior to the measurement of PSS, the soil was double ploughed to a depth of approximately 850 mm, first in a north-south (N-S) direction and then in the east-west (E-W) direction. PSS was measured with a hydraulically driven penetrometer at a constant speed of 1.83 $m.min^{-1}$ and all data were registered automatically by a microprocessor. The penetrometer was equipped with a cone having an included angle of 30^{o} and a 1.29 cm^2 base area. Measurements were made in 50 mm depth increments from the surface to the 850 mm depth layer at 172 locations on a rectangular grid with the smallest sampling interval being 1 m, and the rest in multiples of 5 m (Figure 1). The soil water content at the time of measurement was brought to field capacity (ca. 15.5%) and found to be remarkably uniform both in space and in depth (20 locations, coefficient of variation, CV=0.101). The homogeneity of the 1 ha study area was further confirmed by textural analysis and bulk density determinations conducted at 15 locations and four depths each. Bulk density, for example had a CV of 0.05.

Initially, standard statistical methods were used to screen the data. The frequency distribution of PSS at all depths was found to be skew. Consequently, geometric and not arithmetic means were used to describe the increase of PSS with depth. When grouped according to measuring position, PSS at depths <400 mm within the tractor row is significantly higher (P=0.05) than within the plant row (Figure 2). The soil layers between 400 and 750 mm do not differ with respect to PSS, irrespective of sampling location but at 800 and 850 mm, PSS in the tractor row again is significantly higher than within the plant row. In view of this it was decided to concentrate the spatial analysis on two depths above (200 & 350 mm), one at (500 mm), and one below (750 mm) the point of PSS coalescence indicated in Figure 2.

After a logarithmic transformation of PSS, macro trends across the field were removed with a second order median polish (Hamlett et al, 1986). The resulting residuals were normally distributed and complied to the required second order stationarity for a geostatistical analysis. The spatial structure of the residuals of PSS at the four selected depths was analysed by using geostatistical methods. The theory of geostatistics and its application to soil science have been reviewed extensively e.g. Webster (1985) and Trangmar et al (1985) and with the exception of certain terms, will not be repeated here. In brief, geostatistics can be summarised as a method that describes spatial variability in two parts: variography and kriging. In the present study variography which is the estimation and modelling of the spatial stucture of variation and covariation, was used.

The degree of spatial dependancy of PSS can be analysed with semivariogram functions. The semivariogram $\gamma(h)$ is estimated using

$$\gamma(h) = (2N(h))^{-1} \sum_{i=1}^{N(h)} (PSS_i - PSS_{i+h})^2 \quad ....(1)$$

where h is the separation distance in lags between sampling points, N(h) is the number of pairs of observations at lag h, and PSS is the penetrometer soil strength at position i. A plot of γ vs. h is called the semivariogram. The separation distance at which the semivariance reaches a maximum value (if such a point occurs) is called the range a, and the particular γ at that distance is called the sill. Points closer than a are spatially dependent, while points further apart bear no relation to one another. The intercept of the semivariogram is termed the nugget variance, C_0, and represents unexplained or "random" variance, often caused by measurement error or microvariability of the property which cannot be detected at the scale of sampling.

RESULTS.

The semivariance, γ, of the PSS residuals were calculated using equation 1 and the semivariograms of the four depths are graphically presented in Figure 3. The semivariance γ increased progressively (albeit somewhat erratically) with separation distance at all four depths, but the rate of increase is more pronounced in the shallower layers. Inspection of the semivariance of the 350 and 750 mm depth suggest anisotropy which is indicated by the consistent difference in the semivariance of the two directions.

In all four cases a spherical model with sill fitted the data well and is of the form (McBratney & Webster, 1986):

$$\gamma(h) = C_0 + C[3h/2a - 1/2(h/a)^3]$$

where a is the range of the spherical model and the other parameters defined as before. It should be mentioned that, according to Journel and Huijbregts (1978), γ as an estimator of the semivariance is unreliable for $N(h) < 50$. In the present study, N(h) met this requirement at the 5, 10, 15 and 20 m separation distances only (Fig 3) and consequently, this requirement was slightly relaxed to $N(h) > 35$ to include the 1, 2, 25 and 30 m distances as well. γ at 35 and 40 m are included in Figure 3 for comparative purposes only. The range of influence was calculated using the method proposed by Vieira et al (1983). The range, sill, nugget variance (absolute and as a percentage of the sill) and the population variance of the transformed data are listed in Table 1.

In the case of anisotropy, the semivariogram computed in the direction of maximum variation will have the steepest slope (A), while that in the direction of minimum variation will have the lowest slope (B) (Trangmar et al,1985). The ratio of the two slopes, A/B, can be used as a guideline to support the choice of anisotropic models. The A/B criteria indicate anisotropy at 350 mm but not at the 750 mm depth. The range and sill for both the isotropic and anisotropic cases of 350 mm are listed in Table 1.

Table 1. Parameters defining the spatial structure of PSS.

Depth (mm)	Nugget Abs.	%	Range (m)	Sill [Log(kPa)^2]	Sample variance. [Log(kPa)^2]
200	0.022	20	8.5	0.110	0.090
350(iso)	0.041	35	10.4	0.117	0.084
350(N-S)	0.032	22	14.5	0.147	0.084
350(E-W)	0.044	45	6.5	0.097	0.084
500	0.032	36	9.2	0.089	0.072
750	0.062	78	9.1	0.079	0.074

DISCUSSION.

Analysis of the semivariograms indicate that PSS is spatially structured and not randomly distributed in space. This is especially true for the shallower soil depths(200 and 350 mm). With the exception of the 350 mm layer, the range of influence is approximately 9 m. Both the sill and the sample variance decreased with depth while the nugget variance C_0, both absolute and as a percentage of the sill, increases with depth. This suggests that the well defined spatial structure of PSS in the shallower soil layers, declines with depth and is possibly related to the fact that the natural spatial structure was destroyed by the initial deep ploughing . The secondary tillage actions recompacted the shallower layers and either reintroduced the original spatial structure, or induced new structures with ranges of the order of 9 m. The spatial dependency means that sampling intervals during any future study of PSS on this soil should not exceed the average range of approximately 9 m.

No definite explanation for the anisotropy at 350 mm could be found but the consistent higher variance at the 750 mm depth in the E-W direction can be explained in terms of the effective maximum working depth and the direction of the initial tillage practice. The first ploughing direction was N-S and effectively loosened the soil to a depth that varied between 750 and 850 mm but also created unwanted underground ridges of undisturbed soil on either side of the travelling paths of the share. Due to the soil lift, the share did not reach these ridges with the second E-W pass. Measuring PSS in the E-W direction therefore randomly fluctuates between the low values of the loosened soil and the higher values of the more dense undisturbed ridge and increases the variation in this direction. Along the N-S transects, measurements are made either in loose soil or in an compacted ridge for the whole length of a transect.

Part of the nugget variance may be due to sampling and measurement errors but the small absolute values of the nugget variance, specifically at 200 mm and 350 mm, indicate that such errors were minimal. It furthermore underlines the value of a penetrometer as an instrument to study the spatial distribution of soil strength.

CONCLUSIONS.

Penetrometer soil strength has a log-normal frequency distribution and a considerable amount of spatial variation. Eventhough in terms of texture and other physical properties such as water content at field capacity and bulk density, this field is regarded to be very uniform, the penetrometer soil strength was found to be spatially dependent. The average range of influence between samples for the four depths that were analysed was approximately 9 m and with the exception of the 350 mm depth the spatial structure of PSS is isotropic. The definition of the spatial structure, as expressed by the range, and the nugget variance as a percentage of the sill, declines with depth. The penetrometer proved to be a usefull tool for a study of this kind because a large number of locations can be sampled accurately in a short time.

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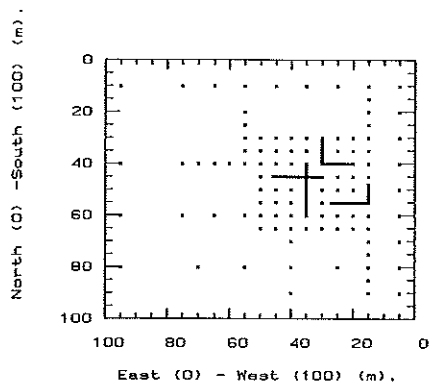

Figure 1. Sampling locations for the determination of PSS. The solid lines indicate 1 m sampling intervals.

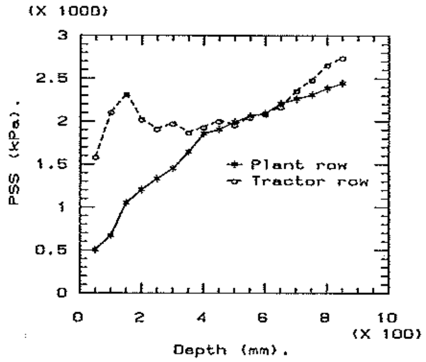

Figure 2. Geometric mean PSS as a function of depth and measuring position.

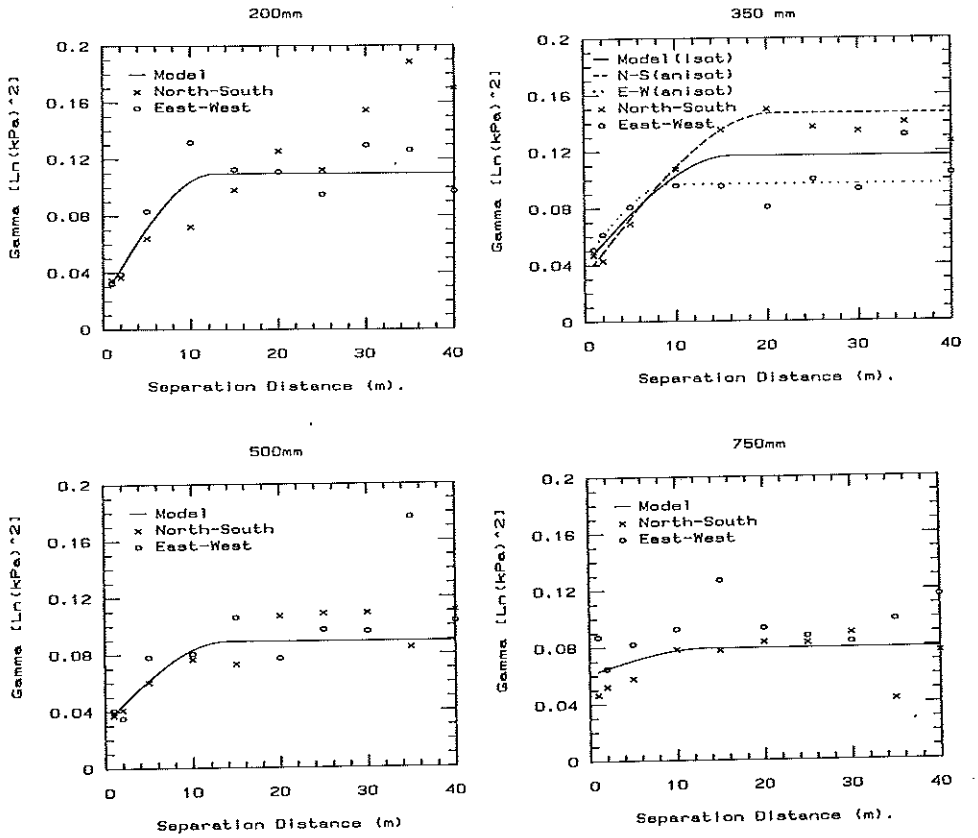

Figure 3. Semivariograms of the 200, 350, 500 and 750 mm depths with a spherical model fitted to the data.

STATISTICAL ANALYSIS OF CONE INDEX READINGS IN PADDY FIELD SOILS

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SUMMARY

Some cone penetrometer tests were carried out in a paddy field and in a soil bin. The results show that the statistical distribution of cone index CI depends on the homogeneity of soil.This feature should be considered in the determination of average cone index of soil.

I. INTRODUCTION

It is well known that cone index in paddy field soils is a random variable with large variance. The suitability of cone index for use in paddy fields is a problem in dispute.In this paper, the variation of cone index in paddy field soils and the problem of sampling are considered.

II. EXPERIMENTS

1. Method: Cone indices were measured in the paddy field and soil bin. 200 measurements were taken at equal interval in an area of $10*1m=10m^2$ in the soil bin. The results were representative of the whole test area. The sampling density in the field was less.

2. The treatments and main physical properties of cone index CI:In a 6*21m soil bin, ten meters in the middle was selected as the test area. Before test, it had been drained to consolidate for half a year, and then, water was poured in to soak it for two months, to keep it in a saturation condition similar to the real paddy field.In the paddy field, water was poured in and soil was soaked for several months after ploughing and was very soft. The depths of loose soil and water on the field surface were 200-250mm and 50-100mm respectively.

The soil in the soil bin and the field were the same. The main physical properties of the soil are shown in table 1.

3. Apparatus: An electronic cone penetrometer with an extended octagonal ring transducer was used. The depth of penetration was measured by an accurate multi-circles resistor. The data were processed by the computer.

4. Statistical test of the distribution of cone indices:

According to K.Kogure(1985), in high moisture content,

TABLE 1 Soil properties

Particle analysis	Sand (>0.01mm)		Clay (< 0.01mm)		
	>0.05mm	0.05-0.01mm	0.01-0.005mm	0.005-0.001mm	<0.001mm
(%)	45.83	11.47	7.3	16.65	18.7

homogeneous soils, the values of cone indices can be regarded as normally distributed . The goodness of fit of the normal distribution can be tested by chi-square methed.

$$X^2=\sum_{i=1}^{k} \frac{(V_i-nP_i)^2}{nP_i} \qquad (1)$$

If $X^2 < X^2_{1-\alpha,f}$

then it can be concluded with 100(1-α) percent confidence that the values of CI fit the normal distribution well.Otherwise the null hypothesis will be rejected and other types of distribution should be considered.

III. RESULTS

The depth of measurement in soil bin is 300mm. The results are divided into three layers (0-100,110-200,210-300mm), two layers (0-150,160-300mm) and one layer (0-300mm) separately, and the mean values of CI in each layer are calculated. In the field, the depth of measurement is 200mm. The results are divided into two layers(0-100,110-200mm) and one layer separately. *The frequency histogram and the density curves of* normal distribution calculated from the data are shown in Fig.1. The results of the Chi-square tests at 95% confidence are shown in table2.

TABLE 2. The Chi-square tests on CI normal distribution

NO.	Places	Layer(mm)	Sample numbers	Mean CI	S.D.	X^2	D.F.
1	soil	0-100	200	3.59	1.16	11.34	7
2	bin	110-200	200	5.92	2.09	33.30	7
3		210-300	200	5.04	1.60	29.04	7
4		0-150	200	4.42	1.43	12.29	7
5		160-300	200	5.27	1.23	23.17	7
6		0-300	200	4.85	1.17	18.87	7
7	field	0-100	203	0.12	0.104	760.35	7
8	in the	110-200	188	1.09	0.91	4592.8	7
9	farm	0-200	187	0.58	0.48	1066.4	7

* when $\alpha=0.05$, $X^2_{1-\alpha,7}=14.1$

The results in table 2 show that most of them cannot pass the Chi- square test. It indicates that the cone indices CI are not always coming from the normal distribution population

IV. Discussion

1. The distribution of CI in paddy field soils:Our results are different from those of K.Kogure's. The reason may by due to the difference of the soil conditions. K.Kogure tested in the "homogeneous soil layer". Our soil conditions were similar to those in the actual field and the homogeneity was rather poor. There were many clods of different size which may have caused the deviation of CI from the normal distribution.

We consider that the Weibull distribution is more suitable for describing the value of CI in paddy field soils.

The distribution function of Weibull distribution:

$$F(CI)=\begin{cases} 1-\exp\left[-\dfrac{(CI-r)^m}{t}\right] & CI >= r \\ 0 & CI < r \end{cases} \qquad (2)$$

where m, t , r represent the parameters of shape, scale and location separately.

The Weibull distribution has an important property, when m=3.75, it approximates to the normal distribution. It is convenient therefore to use it for representing the distribution of CI in the paddy field, no matter whether the soil layer is homogeneous or not.

The Weibull desity curves of CI are shown in Fig.1. The three parameters m, t , r and the results of Chi-square test are shown in table 3.

TABLE 3. The Chi-square test on CI Weibull distribution

NO	Place	Layer (mm)	Sample numbers	m	t	r	X^2	D.F.
1	soil	0-100	200	3.49	129	0	10.24	7
2	bin	110-200	200	1.95	15.5	2.35	13.8	7
3		210-300	200	3.15	50	2	6.77	7
4		0-150	200	2.15	15.2	1.35	9.83	7
5		160-300	200	2.33	17	2.38	10.71	7
6		0-300	200	2.4	14	2.3	8.95	7
7	field	0-100	203	1.05	0.11	0.02	13.07	7
8	in the	110-200	188	1.1	1.2	0.08	13.69	7
9	farm	0-200	187	1.1	0.6	0	8.76	7

* when $\alpha=0.05$ $X^2_{1-\alpha,\ 7} = 14.1$

The distributions of CI in all cases pass the Chi-square test. It means that they come from the Weibull population. The m values of some distributions approximate to 3.75 and the shape of these curves are similar to the curve of normal distribution. This indicates that our results are not in contradiction to K.Kogure's. His research was a special situation of "homogeneous soil".

2. Determination of measurement number n for estimating the population CI value

According to sampling theory, no matter what kind of distribution the population X is, sample $\bar{x}= x/n$ can be used to estimate the population . The only problem lies in the sampling number n to give the same accuracy for different population distributions. In a fairly homogeneous soil, CI values can be considered as the normal distribution. Then the sampling number n can be calculated by

$$n=1.96*[cv]^2/d^2 \qquad (3)$$

where d——accuracy coefficient cv——variable coefficient

If data comes from a soil where the homogeneity is poor, the CI values should be considered as coming from Weibull distribution. According to sampling theory, in the case of non-normal distribution, the sampling number should be large, generally, more than 30. If we can't sample so many, it is better to reject some data which constitute a large departure from the others so as to promote the accuracy of the result.

V. CONCLUSIONS

1. The distribution of CI value in paddy field can be described generally by a Weibull distribution, and will tend towards a normal distribution when the homogeneity of the field is better. In this special case, the conclusion agrees with K.Kogure's.

2. The sampling number n for estimating the mean value of CI in the field can be determined from the normal distribution sampling formulae $n=1.96*[cv]^2/d^2$ when the field is homogeneous. Otherwise, it is better to take the sampling number n bigger than 30. If this can't be achieved, those data which constitute large departure from the others should be rejected.

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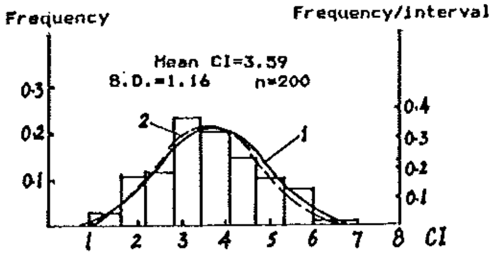
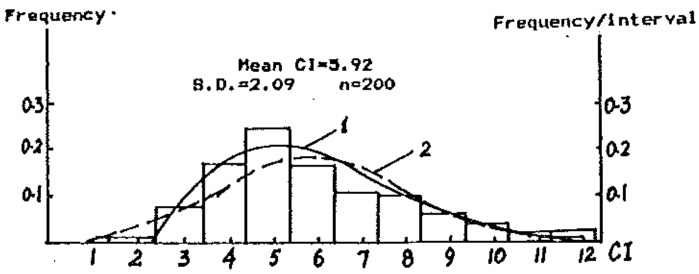
Fig. 1. the frequence histogram and probability distribution of cone indices in faddy field soil

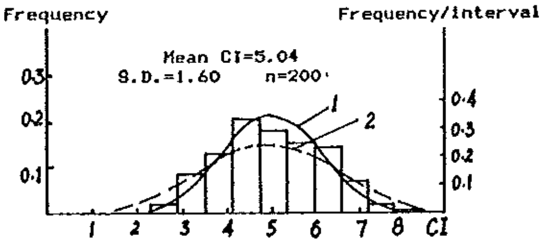
1—— Weibull distribution 2—— Normal distribution



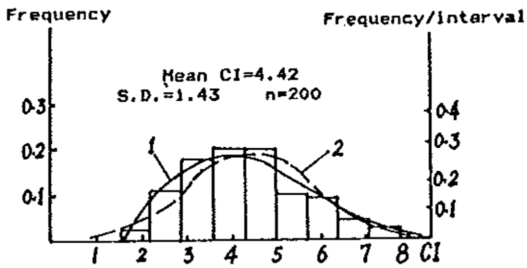
(a) 0-100mm (soil bin)



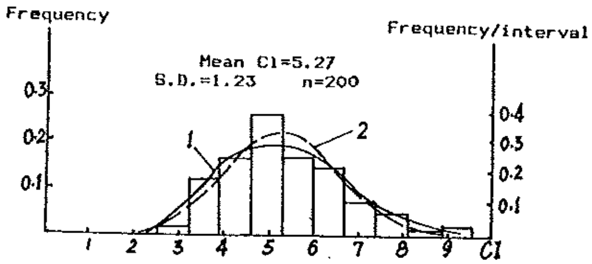
(b) 110-200mm (soil bin)



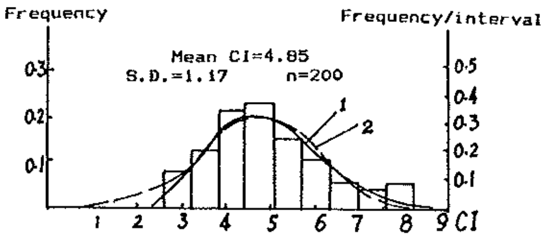
(c) 210-300mm (soil bin)



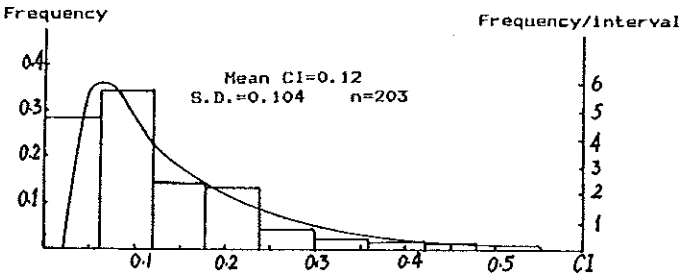
(d) 0-150mm (soil bin)



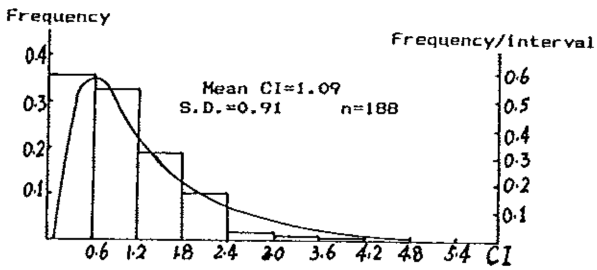
(e) 160-300mm (soil bin)



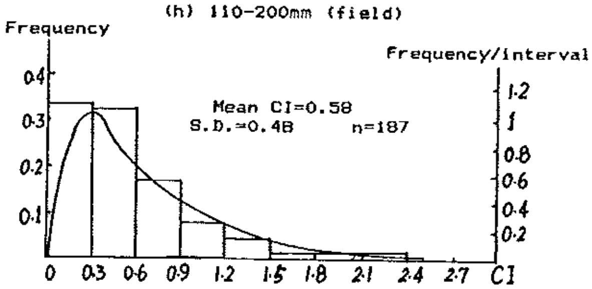
(f) 0-300mm (soil bin)



(g) 0-100mm (field)



(h) 110-200mm (field)



(i) 0-200mm (field)

INFLUENCE OF AERATION CONDITIONS IN THE SEEDBED ON SUGAR BEET SEED GERMINATION : EXPERIMENTAL STUDY AND MODEL.

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ABSTRACT

Sugar beet seed germination was studied, in laboratory conditions, according to the aeration conditions in the seedbed. Soil structural characteristics such as structural void ratio, aggregates diameter, soil confinement and soil microbial respiration, were considered. Relative gas diffusion coefficient, soil and seed oxygen uptakes were measured. A model of oxygen transfert, based on laws of gas diffusion (Fick's laws), is proposed in order to predict germination. It allows the calculation of the oxygen concentration around the seed. Germination is predicted on the basis of the relationship between oxygen concentration and germination. Differences between observed and simulated germination are discussed.

INTRODUCTION

Poor emergence, in wet conditions or for crusted soils, is often attributed to hypoxia conditions in the seedbed, i.e. to a reduction of the oxygen concentration. But, it is difficult, in field conditions, to characterize the conditions of hypoxia, to predict their occurence in the seed bed and their consequences on the crop. The problems induced by hypoxia conditions during emergence are particulary important for sugar beet :
(i) this crop, having no ramification, is very sensitive to problems occuring during the emergence phase,
(ii) in the north of France, for the last ten years, sugar beets have been sown earlier in order to increase the length of the photosynthetic cycle, but a higher risk to have a rainfall period has been introduced.

Low oxygen concentration during emergence can affect both seed germination sensu stricto and growth of the embryo. In most studies, those two phases are not distinguished, and their respective influence on emergence is not well known. In this study, we were only interested in germination. We investigated, both experimental and model way, the relationships between aeration conditions in the seed bed and sugar beet seed germination.

MATERIAL AND METHODS

Plant material : non pelleted monogerm sugar beet seeds, cv. ATLAS (Etablissement Mennesson, Anizy Le Chateau, France), calibrated between 3 and 3.25 mm after rubbing, were used.

Soil samples : soil samples were prepared by standard compaction, in a cylindrical cell of a known volume (2.4 cm height, diameter of 7 cm), of a mass of aggregates calculated according to the required soil structural characteristics and water content. Aggregates were obtained by dry-sieving between 1-2 mm, or 2-3 mm. Aggregates were first saturated under vacuum at a water matric-potential of -0.3 kPa ; then they were dried under silicagel, down to the required water content. To avoid a limiting effect on imbibition of the seed, minimum water potentials were higher than -20 kPa. Intra-aggregates porosity (textural porosity), was always saturated: the inter-aggregates porosity (structural porosity) was the air filled porosity. In order to create situations where structural voids could be partially filled with water, compacted samples were prepared as above, and, subsequently to saturation (0 kPa), placed on tension tables at the required water matric-potential.

Germination tests: fifteen seeds were placed in each soil sample, at medium height. Two particular treatments were combined with the experiments described above and dedicated to soil structure,. In order to induce a high soil microbial activity, glucose (1 mg C-glucose.g^{-1} dry soil) was added. To limit the available volume of oxygen, some samples were confined to avoid oxygen exchange between the soil sample and the atmosphere. Temperature was constant (20°C ± 0.5).

Soil diffusion parameters: relative gas diffusion coefficient was determined on the same soil samples than those used for germination tests. The method of Ball et al. (1981), based on the diffusion of Krypton-85, and the estimation procedure of Bruckler et al. (1988), were employed.

Oxygen consumption: a gas (80% N_2, 20% O_2), moistened by bubbling through water, passed into a jar (with a gas flow of 6.7 $cm^3.s^{-1}$) which contained the moistened aggregates (100 g at a potential of -20 kPa), with or without glucose. At the output of the jar, the CO_2 concentration was measured with an infrared gas analyser (ADC mark II). The respiratory quotient was supposed to be 1 in order to estimate the soil oxygen uptake.

RESULTS

In optimal conditions of germination (ISTA recommandations), the maximum germination percentage was reached during the fourth day after the beginning of imbibition, and final germination percentage was 95%.

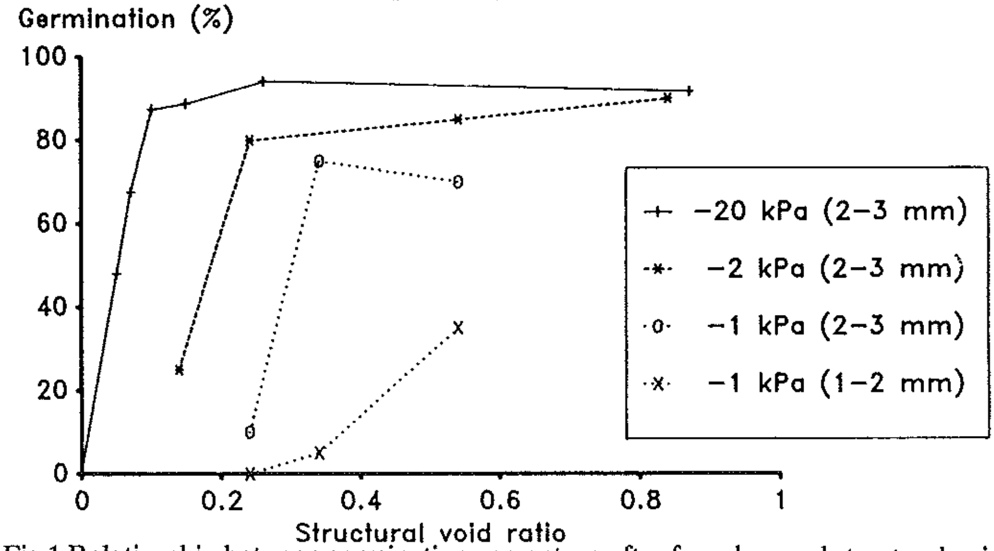

Fig.1 Relationship between germination percentage after four days and structural void ratio, for different water matric-potentials and different diameters of aggregates

Figure 1 shows that at -20 kPa, germination percentage was reduced only for high compaction level. Germination began to be slightly affected when the structural ratio was lower than 0.2 (10% air-filled porosity), and was greatly affected only when the structural void ratio was lower than 0.1 (5% air-filled porosity). Structural void ratios inducing a reduction of the germination percentage, were higher for high water matric-potential (-2 or -1 kPa) and depend on diameter aggregates.

Table I.

Sugar beet germination percentage after four days, according to structural void ratio, soil oxygen uptake and soil confinement (the water potential was -20 kPa).
Low and high soil oxygen uptake corresponded approximatively to $0.3.10^{-3}$ and 3.10^{-3} mm^3 oxygen per second and per gramme of dry soil.

		structural void ratio		
		0.05	0.15	0.25
soil sample confinement	soil oxygen uptake			
no	low	48%	89%	94%
	high	3%	86%	
yes	low	7%	80%	95%
	high	0	0	

Table I shows that soil microbial respiration and soil confinement can also modify germination. Soil confinement may occur when soil surface presents a saturated crust which prevents any oxygen exchange with the atmosphere. In an unconfined sample, germination was dependent on soil microbial respiration only if the structural void ratio was very low (0.05). In a confined sample, a high soil microbial activity inhibited the germination ; the germination percentage was reduced by a low soil microbial respiration for structural void ratio lower than 0.2.

These results show that compaction level, water matric-potential and soil confinement, and soil respiration interact with aeration conditions in the seed bed, and can modify sugar beet germination. But apparently only high compaction level (air-filled prosity lower than 10%), or high water potentials can significantly reduce germination.

Diffusion is the main process involved in gas transfer in soil. Gas diffusion in soil can be described by the Fick's laws which, in monodimensional geometry, are :

(1)...................................... $q_x = - D_x \, . \, dC / dx$

(2)...................................... $E \, . \, dC / dt = - d(q_x) / dx - P$

where :
Ox is the flux direction, q_x is the gas flux, D_x is the gas diffusion coefficient,
C is the gas concentration, E is the transfer porosity, P is the soil oxygen uptake.

Figure 2 shows the relative gas diffusion coefficient according to structural void ratio, water potential and aggregates diameter. Considering only the results obtained on soil samples at -20 kPa water potential (where the structural porosity was only filled with air), a statistical relationship, like Currie (1960), between relative gas diffusion coefficient (D/D_o) and air-filled porosity (E) can be established, with a correlation coefficient of 0.989 :

(3)....................$D/D_o = a \cdot E^b$ with a = 3.22 and b = 2.55

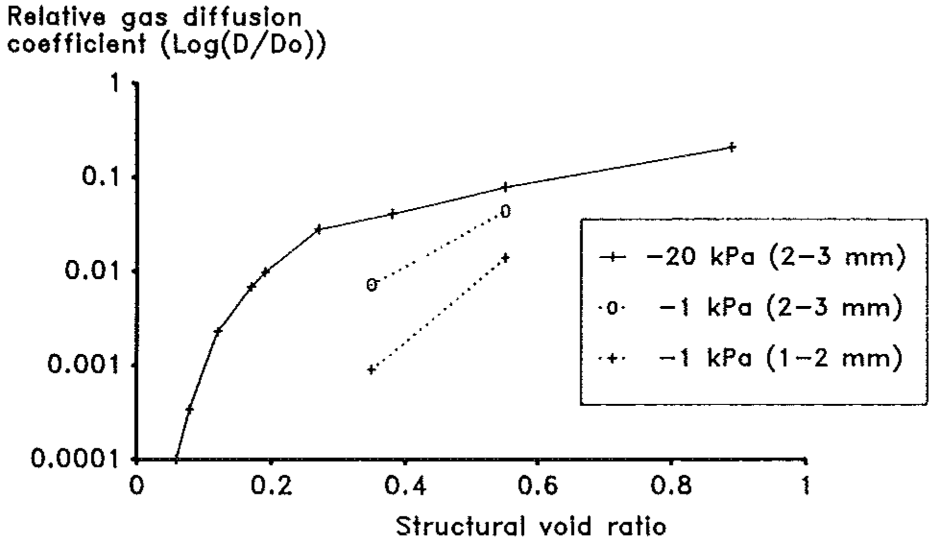

Fig.2 Relationship between relative gas diffusion coefficient and structural void ratio for different water matric-potentials, and different diameters of aggregates

Relative gas diffusion coefficients were lower, at -1 kPa than at -20 kPa water potential, specially with aggregates having a mean diameter of 1-2 mm. At -1 kPa water potential, there was water in the structural porosity, and for a given structural void ratio, air-filled porosity was lower than that at -20 kPa. Moreover, even at the same air-filled porosity, relative diffusion coefficient was lower at -1 kPa ; at such a water potential, water menisci in the structural pores would probably increase the tortuosity, or even isolate trapped-air volumes. These results illustrate that it is not possible to find an unique relationship between gas diffusion coefficient and air-filled porosity.

The oxygen concentration around the seed can be calculated with the equations (1) and (2) and the associated parameters (Fig. 2 and Tab. I). Transfer porosity has been assumed to be equal to air-filled porosity. Seed oxygen uptake during germination was less than $1.4.10^{-3}$ $mmm^3.s^{-1}$ by seed (Richard et al., 1988). In order to predict germination, a relationship between oxygen concentration and germination has been established (Richard et al., 1988). The figure 3 shows that, in 10% oxygen, germination was only slightly reduced and that in 1% oxygen germination was inhibited. So if during germination, the oxygen concentration around the seed is higher than 10%, germination percentage after four days must be maximum.

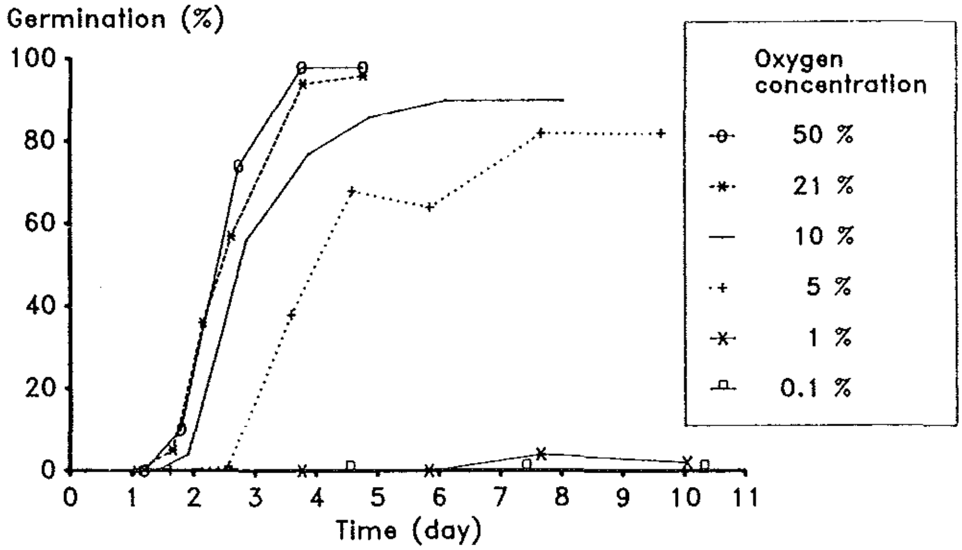

Fig.3 Relationship between germination and O_2 concentration

The soil was assumed to be homogenous and isotropic, and the seed was considered to be of a cylindrical shape. The "soil-seed" system had an axi-cylindrical geometry with a radial symetry and it could be described by two coordinates : radius and height. We assumed that the oxygen uptake by the seed was homogenous at the seed external surface. The variation of the soil oxygen uptake with oxygen concentration was considered (Richard and Guérif, 1988a). Equations (1) and (2), in cylindrical coordinates, have been computed with numerical process.

A good agreement was found between observed and predicted germination (Richard, 1988), except for two kinds of situations, (i) in the unconfined soil samples with very low structural void ratio, (ii) in soil samples at high water potential, where germination was reduced although calculated oxygen concentration was higher than 10%.

In the last situation (ii), the difference was probably due to the presence of a water film around the seed. The difficulty to estimate the water film thickness prevented to include it in the model.

In the first situation (i), different hypothesis can explain the difference (Richard, 1988) :
- the soil sample was not homogenous at high compaction level. Some seeds can be not connected with atmosphere. Experiences showed that germination of seeds rubbed with a saturated soil (with only a textural porosity), 1 mm thick, was inhibited.
- the sugar beet seed has a particular structure : the embryo is surrounded by a pericarp which may have specific entrance ways for oxygen to the embryo, like the basal pore (Perry and Harrison, 1974). In the soil sample, these ways may be stopped by an aggregate, and oxygen can not diffuse to the embryo. Experiments showed that, when the basal pore was stopped, the germination of 10 to 20% of the seeds was inhibited.

- seed-gas contact area may limit the oxygen uptake by the seed, and then influence germination. Experiences showed that germination could be affected when less than 15% of the external seed surface was in contact with the atmosphere if the oxygen concentration was lower than 10% .

CONCLUSION

(1) The germination of sugar beet seed may be affected by any of the soil characteristics that modify the gas diffusion parameters, such as the structural characteristics (structural void ratio, aggregates diameter, confinement), the water potential, and the soil microbial respiration.

(2) A physical model of oxygen transfer, based on gas diffusion's laws, can predict the situations where the germination may be affected or not, in a wide range of germination conditions, except when the close surroundings of the seed have a great importance. In the latter case, germination can be reduced independently of the oxygen concentration within the whole sample. The close seed surroundings (water film around the seed, seed-gas contact area) are not taken into account in the estimate of the relative gas diffusion obtained at the scale of the whole soil sample.

(3) Nevertheless, such a model can be used to predict oxygen concentration level in the seedbed, and situations where germination may be affected in the field conditions (Richard and Guérif, 1988a and b).

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CEREAL YIELDS AND SOIL PHYSICAL PROPERTIES IN RELATION TO THE *DEGREE OF COMPACTNESS OF SOME NORWEGIAN SOILS*

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SUMMARY

The concept of the relative degree of compactness facilitates comparison of the compaction state of soils with varying mean particle density and total porosity. Such variations limit the usefulness of bulk density data alone when comparisons are to be made between trials on different soils. The concept entails the relation of field bulk density values to a standard value measured in the laboratory. Cereal yields were found to decline sharply at values above 90% . Data for the pore size distribution of soil samples from 14 compaction trials was related to bulk density and to the relative degree of compactness. The correlations of air capacity and air permeability were higher with the latter than with bulk density. Data from 29 sites was used to derive an equation for predicting the standard degree of compactness from soil organic matter, texture and gravel content.

INTRODUCTION

A means of comparing the compaction state of different soils is required for the interpretation of the effects of traffic on crop yield. Detailed analyses of pore size distribution are too slow and expensive for routine use, whilst bulk density measurements alone are of little value for comparing soils with widely varying contents of organic matter and gravel. Measurements of shear strength and penetrometer resistance give useful guidelines, but vary with soil moisture content and cannot be used in stony soils.

The concept of the standard degree of compactness was introduced by Håkansson (1966) as the basis of a reference index. The method entails the determination of the dry bulk density of wet soil subjected to a long-term, uniaxial static pressure of 200 kPa under confined, freely-drained conditions. Field values of bulk density are expressed as percentages of this value.

The usefulness of the concept is demonstrated here for some Norwegian soils.

METHODS AND MATERIAL

Data for the relationship between cereal yield the soil compaction state in the central topsoil layer (10-20 cm) are derived from eight compaction trials conducted in southeast

Norway (Njøs 1978, Riley 1983). Treatments included various numbers of wheelings over the entire soil surface, prior to seed-bed preparation in spring. Yield data are expressed as percentages of the yield on untrafficked plots. The results include data from three trials on morainic loam, two on silty clay loam and three on silty loam.

Data for the comparison of related soil properties with the relative degree of compactness, are derived from four compaction trials in cereals and ten compaction trials in grass leys, all in south-east Norway. The results include data from seven trials on morainic loam, three on silty clay loam, one on clay loam and three on silty loam. Pore-size analyses were performed on 314 samples using pressure-plate equipment, and air permeability was measured at pF 2.

RESULTS

Soil compaction and cereal yield

The relationship of relative cereal yield to the soils' compaction state, expressed as (a) dry bulk density and (b) relative degree of compactness, is shown in figure 1. The latter method clearly gives a better explanation of the results than bulk density alone. The optimum degree of compactness for crop yield was about 85% in these trials. Exact agreement of the data is unlikely, since in some trials the soil of the untrafficked treatment may also have been too compact for optimum yield.

Soil compaction and related soil physical properties

A summary of the data used is given in table I. The correlations of some soil physical properties with dry bulk density and the relative degree of compactness, are shown in table II.

Table I. Mean values and standard deviations (SD) of some soil physical properties of the soil samples studied.

Property	Morainic loam n = 134		Clay loam n = 102		Silty loam n = 78	
	Mean	SD	Mean	SD	Mean	SD
Dry bulk density kg/l	1.31	0.11	1.31	0.10	1.25	0.09
Rel.deg.compactness %	85.9	5.8	90.5	6.1	91.9	5.3
Porosity %	49.9	4.0	50.6	3.7	52.5	3.2
Air cap. at pF 1.3 %	11.3	5.2	7.5	4.7	7.7	3.7
Air cap. at pF 2 %	15.5	6.3	9.0	4.9	9.9	3.8
Air perm. at pF 2 μm^2	14.2	14.2	7.0	8.8	3.6	5.7
Avail. water cap. %	26.8	4.8	28.1	3.6	36.8	3.0
Non-avail. water %	7.5	2.8	13.5	2.6	5.7	8.1

n = number of samples

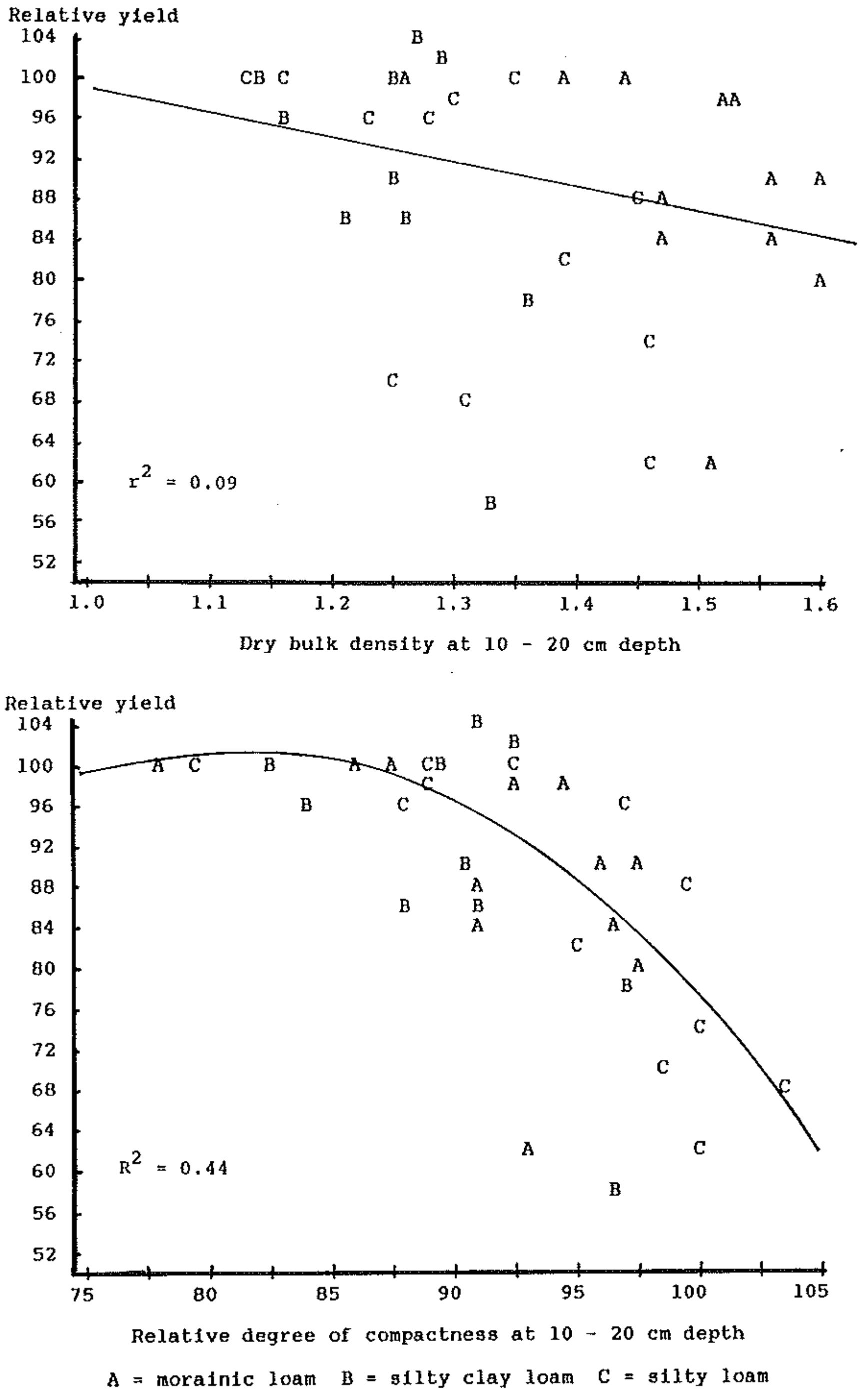


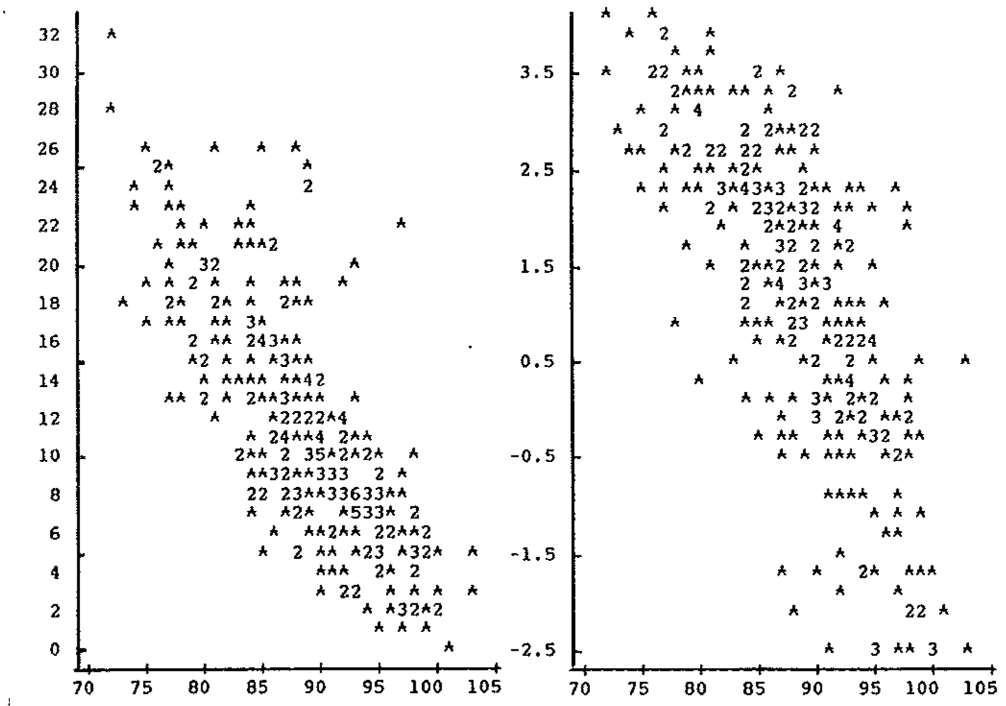
Fig. 1. Relative cereal yield in relation to dry bulk density (kg/l) and the relative degree of compactness (%) in eight compaction trials (100 = untrafficked).

Table II. Correlations of soil physical properties with dry bulk density and the relative degree of compactness.

	Dry bulk density				Rel.deg.of compactness			
	Loam	Clay	Silt	All	Loam	Clay	Silt	All
Air at pF 1.3	-0.37	-0.79	-0.33	-0.41	-0.65	-0.82	-0.84	-0.77
Air at pF 2	-0.32	-0.81	-0.45	-0.37	-0.63	-0.84	-0.88	-0.77
Air perm.	-0.51	-0.67	ns	-0.38	-0.59	-0.75	-0.54	-0.66
Log_e air perm.	-0.43	-0.65	ns	-0.29	-0.59	-0.75	-0.68	-0.73
Avail. water	-0.32	-0.25	-0.39	-0.38	ns	+0.23	+0.39	+0.32
Non-avail.wat.	ns	+0.44	-0.29	+0.15	+0.22	ns	+0.39	+0.16

Air filled pore capacity and air permeability showed closer negative correlation with the relative degree of compactness than with dry bulk density. Air permeability gave a slightly higher overall correlation when expressed on a logarithmic scale. Air capacity at pF 2 was halved and air permeability was reduced by a factor of six when relative compactness increased from 85% to 95%. Soil water contents were less well correlated. A slight positive effect of the relative degree of compactness was found, whereas the correlation with bulk density was negative.

Air capacity at pF 2 (%) Air permeability (Log_e μm²)



Relative degree of compactness %

Fig.2. The relationship of air capacity at pF 2 and air permeability with the relative degree of compactness.

Prediction of the standard degree of compactness

Data from 29 sites was used to examine the relationship of the standard degree of compactness with soil texture, organic matter (ignition loss) and gravel content. Multiple regression gave the following best-fit equation, with variables included in order of importance:

$$Y\ (kg/l) = 1.751 - 0.032 \times \text{Ignition-loss}(\%) - 0.0032 \times \text{Silt}(\%) + 0.0065 \times \text{Gravel}(\%) + 0.0029 \times \text{Clay}(\%)$$

(R^2 = 0.79, std. error of Y = 0.047)

Measured versus predicted values of the standard degree of compactness are shown in figure 3. The calculated relationship with ignition-loss is shown in figure 4 for various soils, together with measured values.

DISCUSSION

The decline in cereal yield found when the relative degree of compactness exceeds approximately 90% coincides with the reduction of air capacity values to about 10% . The corresponding value of air permeability at pF 2 was approximately $3 \mu m^2$. An air capacity of 10% has often been quoted as the minimum requirement for optimum plant growth. Whether this is due to poor aeration or to mechanical impedance of root growth is uncertain. Penetrometer resistances of 2-4 MPa have been found when relative compactness exceeds 90%. Such values have been reported to limit root growth (Ehlers 1982, Dexter 1986, Gooderham 1977).

CONCLUSIONS

1. The relative degree of compactness describes the conditions for plant growth better than dry bulk density alone.
2. Optimum crop growth occurs at approximately 85% relative compactness, and declines at higher values.
3. The standard degree of compactness may be predicted with reasonable accuracy from soil organic matter, texture and gravel content.

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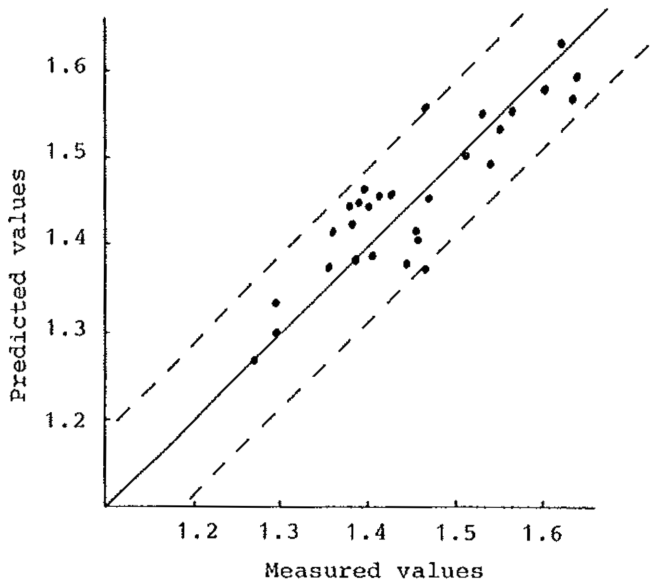
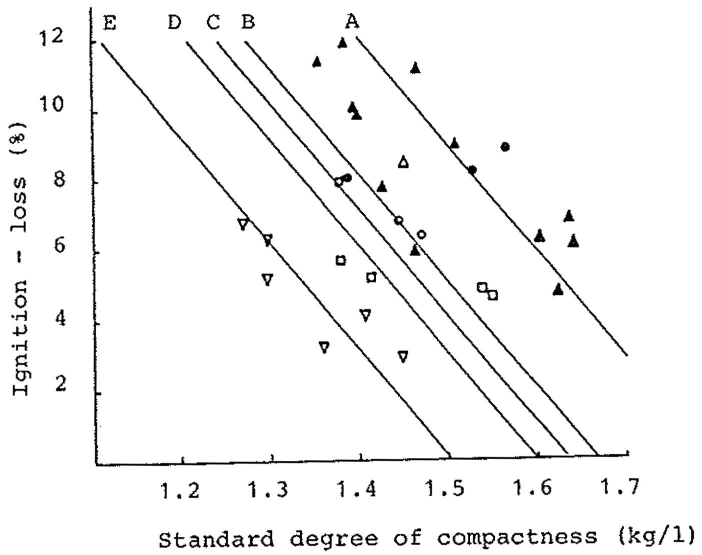


Fig.3. Measured versus predicted values of the standard degree of compactness (kg/l) for 29 Norwegian soils.



	Calculated values		
	Silt%	Clay%	Gravel%
A	45	18	20
B	45	18	0
C	65	30	0
D	65	18	0
E	85	7	0

Measured values

- ▲ Loam (morainic)
- △ Loam
- □ Silty clay loam
- ● Sandy silt loam (mor.)
- ○ Sandy silt loam
- ▽ Silty loam

Fig.4. The relationship of the standard degree of compactness with soil organic matter (ignition-loss).

BIOPORES, ROOTING OF MAIZE AND PHYSICAL SOIL PROPERTIES AS INFLUENCED BY TILLAGE SYSTEMS

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Abstract

The field crop rotation experiment was started in 1977 at the research station of the University of Hohenheim, Ihinger Hof, on a pseudogleye-parabrownearth. Biopores, root mass, root length, soil water and water flow as influenced by plow and rotary hoe were studied. The effects of sampling in or between rows were also taken into consideration. Clear differences, according to tillage systems and sampling location in all the above mentioned parameters were registered. The study took place in 1985 under maize.

1. Introduction

An exact registration of root mass and root length density is important not only for the nutrient and water uptake, but for a C- and N-balance and for the N-fixation too.

The root mass produced by a field crop can be influenced decisively by field history and cultivation practices (rotations, tillage systems, fertilization etc.). When a production system that includes different tillage systems is continued for many years, as in our case, it could cause changes in soil structure, biological activities, in formation and conservation of biopores, in water holding capacity and in root distribution. The biopores can be used from the plants under unfavorable soil conditions as means of rooting in deeper soil layers (Hensen 1892, Graff 1983, Dexter 1985, Gross and Fischer, 1985), Sidiras and Kahnt, 1985 etc.)

The roots of maize are thicker but less branching than roots of cereals, meaning that existing channels or biopores can play a crucial role for earlier and easier rooting in the subsoil. Because of the wide spacing between rows of maize (ca. 75 cm) and in order to record as correctly as possible the root mass, it is necessary to determine the root density between the rows also.

In this paper biopores, root growth (mass and length density) and soil water under maize as affected by two different tillage systems on a pseudogleye parabrownearth are studied. The effects of sampling in or between the maize rows were also taken into consideration.

2. Materials and Methods

The experiment was started in 1977 at the research station of the University of Hohenheim, Ihinger Hof (470-510 NN, average yearly temp. 7.7°C and precipitation 690 mm), on a pseudogleye-parabrownearth (clay and org. carbon in Ap-horizont 20% and 1.5%, in $B_{(g)}$-horizont 30% and 0.5% respectively).

The tillage treatments were conventional plow (ca. 25 cm) and rotary hoe (ca. 10 cm). The investigations reported were made in 1985 under maize (cultivar Eta). The samplings to determine biopore, root mass, root length and physical properties took place in and between the rows of maize after the tasseling stage, in five repetitions for each treatment (for soil water 6).

The number of biopores were counted in the field by a grating of 50 x 20 cm. For the root mass determinations we used a cylinder-sampler of 35 - 12 cm, length x diameter. The root separation from soil was done by sieving. Root mass in biopores was investigated in 12 x 5 cm soil segments. The length of the roots was measured with a method developed by Böhm (1979) as modified by Sattelmacher, (cit. by Mette 1987).

Soil water status was registered gravimetrically on a weekly basis, the samples were taken from 0-10 , 10-20, 20-50, 50-80 and 80-100 cm soil depth. In each tillage system an area of 25 m^2 was kept free of plants as a control. For determinations of saturated water conductivity in 100 cm^3 cylinders, we constructed a special apparatus.

3. Results and discussion

3.1. Biopore area

The number of biopores is a characteristic of the biological activities of soil organisms, especially of worms (Lumbricus terrestris L.) and roots. Figure 1 shows that the biopore area of this soil increased with depth; under rotary hoe it was significantly higher than under plow. Biopore area under rotary hoe was 261%, 25% and only 9% higher at soil depths of 10-30, 30-45 and 45-60 cm, respectively. The significant increase of the biopore area at the two upper layers under rotary hoe can be explained as follows:

1. The destructive action of plow against biopores is approximately three times higher than under rotary hoe.
2. The organic residues after harvest were plowed into deeper layers, leading to unfavorable living and nutrient conditions for the earth worms.

3. If the organic matter is plowed under, the susceptibility to dryness and wetness or to warmth and cold is extreme, affecting life habits of the worms.

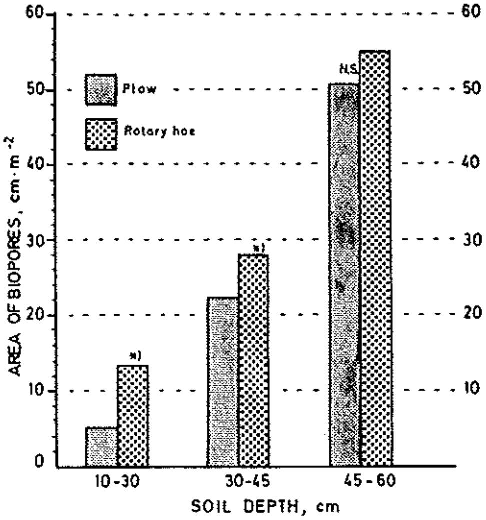

Fig. 1: Area of biopores under maize, as influenced by tillage systems (sampling made August 1985)
*) significant at P= 5 %

4. The absence of cover materials means less protection for the worms against birds and solar irradiation.

3.2 Root mass and root length

Because of the wide spacing between the rows of maize, clear differences in root mass and root length density depending on the sampling location were expected, especially at the upper layers. In Figure 2, it is shown that the root mass density under plow was higher only at the soil depth 0-10 and 10-25, while at the depth 25-50 and 50-80 cm the rotary hoe treatment dominated. Between the rows, the root mass density under rotary hoe was higher than under plow at all soil depths. However, the root mass did not exceed the value of 0.2 $mg.cm^{-3}$. Root mass density in the rows compared to sampling between the rows, was 41-, 4-, 2- and 1.5 times higher at the soil depths of 0-10, 10-25, 25-50 and 50-80 cm, respectively.

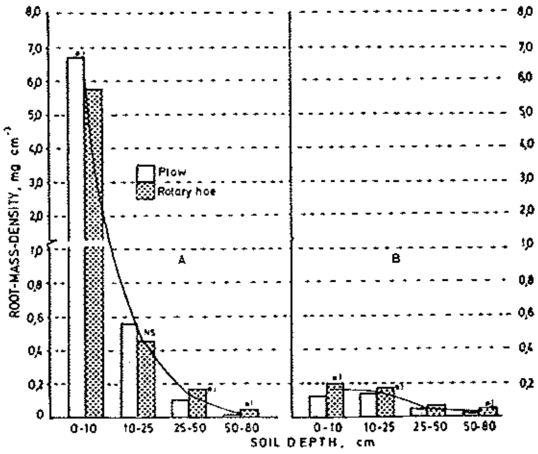

Fig 2: Root-mass-density of maize, after tasseling stage 1985, as affected by the tillage systems and the points of soil sampling (A= in the rows of maize, B= between the rows)
* significant at P= 5%

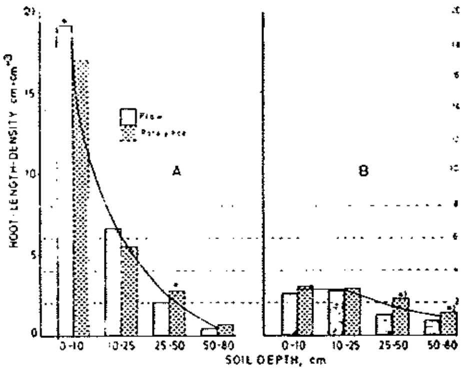

Fig. 3: Root-length-density of maize, after tasseling stage 1985, as affected by the tillage systems and the points of soil sampling (A= in the rows of maize, B= between the rows)
*) significant at P= 5%

The same tendency as above was observed for the root length determination (Fig. 3). For both tillage systems at the layer 50-80 cm, root length density between the rows was twice as high as in the maize rows. At the upper layer of

0-10 cm, root length density rose to 18 $cm.cm^{-3}$ in the rows, but reached only 2.9 $cm.cm^{-3}$ between the rows. At 25-50 and 50-80 cm soil depths, differences in root length between rotary hoe and plow were more apparent between than within rows. This can perhaps be attributed to a more intensive branching of roots growing into the biopores at the soil space between the rows.

Table 1: Root-mass and root-length growth of maize in biopores in percent of the total as affected by plow and rotary hoe tillage systems (after tasseling)

Tillage systems	Root-mass in % of the total		Root-length in % of the total	
	10-30 cm			
Plow	4,1	9,1	3,2	4,4
Rotary hoe	14,0		5,5	
	30-45 cm			
Plow	30,3	38,3	16,7	23,2
Rotary hoe	46,3		29,6	
	45-60 cm			
Plow	51,9	53,8	27,5	29,1
Rotary hoe	55,6		30,7	

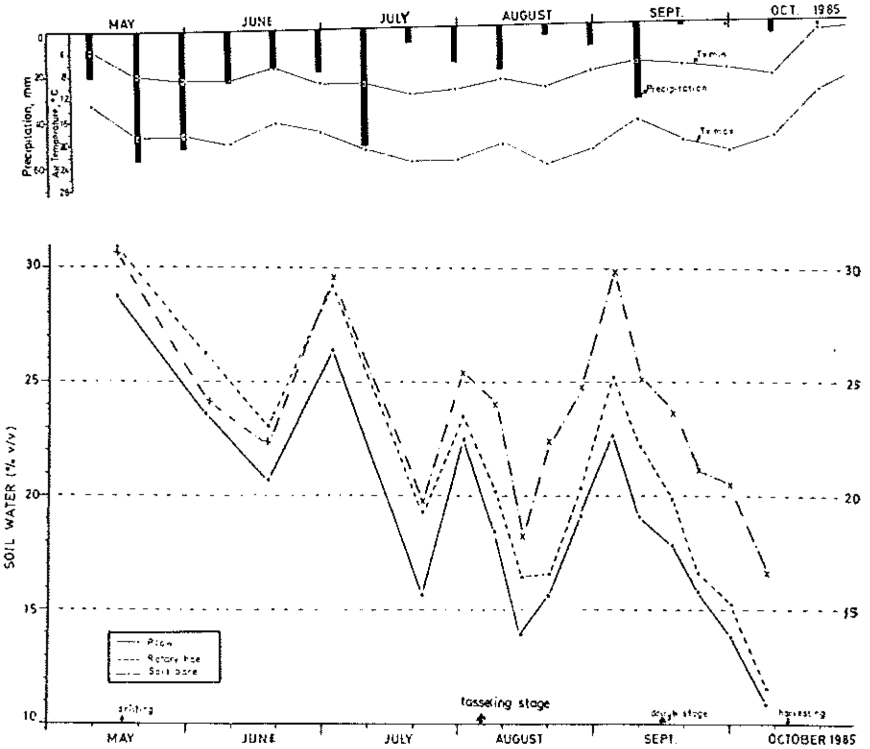

Fig. 4: Water content at the soil depth of 0-20cm, throughout the growth period of maize 1985 under plow and rotary hoe in comparison to the treatment "soil bare".

Table 1 shows, that the root mass density in biopores increased by 9.1%, 38.3% and 53.8% at the soil depths of 10-30, 30-45 and 45-60 cm. Under rotary hoe it was even more evident.

The positive effect of rotary hoe on root length density is not as clear as on root mass density. Generally, roots growing in biopores are thicker but not as intensively branching as those growing outside the biopores, and we did not find any correlation between root mass and root length for the roots developed in biopores.

3.3. Moisture contents and water conductivity

Soil water content throughout the growth period of maize, precipitation and air temperatures are shown in Figure 4. In 1985 from 10[th] Juli to 30[th] August, rainfall was only 58.4 mm.

The rotary hoe persistently showed highest moisture contents. The lowest values of soil water were measured in October. During August, the critical month in our station, soil water volume was maintained between 19% and 14% under plow and between 21% and 17% under rotary hoe. When the soil was left bare (without any vegetation), we registered in the same period 25% and 18% water in the soil. The field capacity (0.33 bar) and the permanent wilting point (15 bar) at the 0-20 cm depth of soil are 29.1% and 13.8%. This means that under plow, soil water dropped below the wilting point on 16[th] of August, 30[th] of September and 7[th] of October, and under rotary hoe this situation was observed only on 7[th] October. Very important is the lowest water regime from May to June under plow in comparison to rotary hoe. It is well known that higher soil moisture correlates negatively with soil temperature, and this, in turn, could mean that the seed bed warmed more quickly under plow than under rotary hoe. Accordingly, the better root growth at 0-25

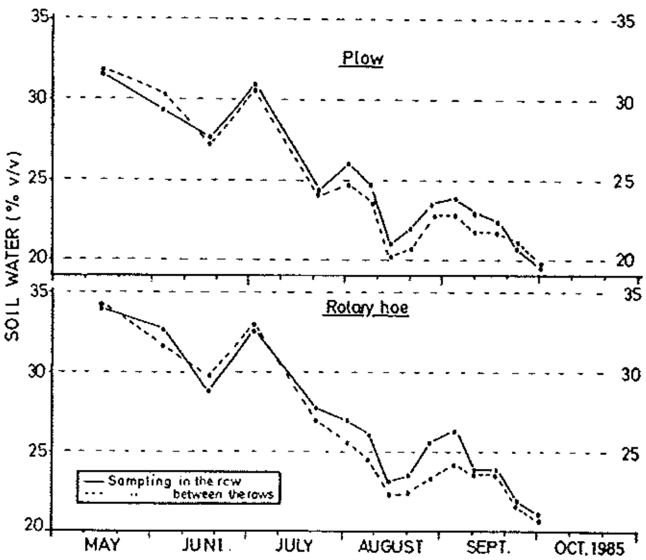

Fig. 5: Soil water content throughout the growth period of maize 1985, by sampling in the row and between the rows, under plow (above) and rotary hoe (below). Average of the depths: 0-10, 10-20, 20-50, 50-80 and 80-100 cm).

cm soil depth under plow had been beneficially influenced, in addition to lower shear strength, by the higher soil temperature also.

Under both tillage systems higher soil moisture conditions were measured in soil areas between the maize rows (Figure 5). From the middle of July until the middle of September the water regime in the rows was unexpectedly higher than the moisture between the rows. And the differences for instance at the upper layer of 0-10 cm, were more than 6% (this will be reported later in a poster). These results could be explained by the following facts:

a) the soil in the rows is better shaded by maize and consequently evaporation is reduced

b) after a precipitation a lot of rain remains on the plants, the interception moisture continues to infiltrate into the soil for a long time after the rain

c) water losses by runoff are higher between the rows, because there are no plant barriers to reduce water velocity (the slope is 5-7%).

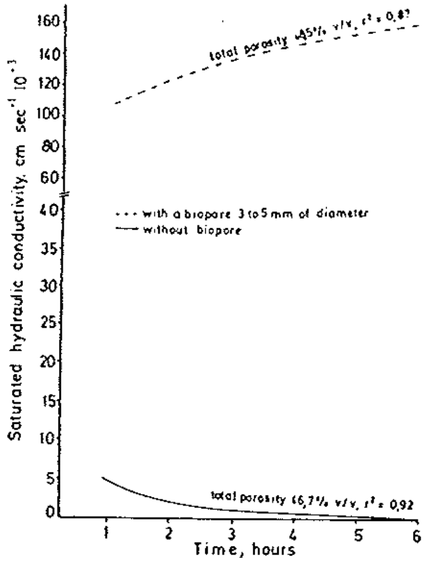

Fig.6: Hydraulic conductivity under saturated-flow as favoreted by biopores (soil depth: 40-50 cm)

The great importance of the biopores for drainage and aeration of the compacted soil layers has already been shown (Ehlers, 1975, Müller et.al., 1985). The saturated water conductivity in samples with one biopore of 3-5 mm diameter, as in our example, was 75 times higher than similar samples without biopore (Fig. 6). In order to take advantage of biopores for crop production, measures to increase the pore continuity become a priority. And in order to conserve and to multiply the biopores in soil, the best possibility appears to be the adaption of less intensive soil preparation methods into the plant production systems.

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STRUCTURAL DEGRADATION OF VERTISOLS ASSOCIATED WITH CONTINUOUS CULTIVATION.

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ABSTRACT

The changes in soil physical and chemical properties associated with up to 64 years of continuous cultivation of wheat were measured in two vertisols of the Darling Downs area of Queensland, Australia. From the various methods of measuring soil structural stability, the percentage of dispersed clay gave the best results when correllated to other physical and chemical properties of the soil. When these properties were expressed on the same basis, i.e. relative to the bulk soil rather than the clay fraction, the amount of exchangeable sodium was well correllated to the amount of dispersible clay which in turn was significantly correllated to the soil hydraulic conductivity. The relationships were independent of soil texture and appears to be common to all vertisols.

INTRODUCTION

Structural degradation as a result of cultivation has long been recognised as a factor in the decline in the physical fertility of the soil. The continuing expansion of dryland arable farming into the semi-arid regions of Australia has raised concern that this form of degradation can seriously affect the sustainability of agricultural enterprises in those environments.

Dalal (1982) and Dalal & Clarke (1984) have shown that the major effect of cultivation on several vertisols of the Darling Downs is a decline in soil organic matter content, resulting in the reduction of chemical fertility and wheat yields. It was thus expected that physical/structural properties of these soils would also be adversely affected. On the other hand, it is generally accepted that the structure of cracking clay soils are less dependent on soil organic matter contents and therefore degradation may not be as severe as on other soils. It is therefore important that the degree of structural degradation on vertisols associated with continuous cultivation, should be evaluated. However, measurements of soil structure were developed based on empirical rather than theoretical considerations and appropriate methods for a particular soil type or group of soil types had not been established. Hence, a method suitable for vertisols should be determined.

This paper reports on the effect of continuous cultivation on the structure of two vertisols and discusses the most suitable method for measuring the structural status of vertisols.

MATERIALS and METHODS

The soils examined were the Waco black earth (Typic Pellustert) and a Brigalow grey clay (Typic Chromustert) from the Darling Downs region of Queensland, Australia, which had been under continuous wheat cultivation. The Waco soil is a deep vertisol of heavy clay texture with a strong self mulching surface. The Brigalow soils consist of two series, the Langlands and Logie series, which are very deep dark grey to reddish brown soils of medium to heavy clay textures with weakly self-mulching surfaces and gilgai development. Some relevant physical and chemical properties of these soils are listed in Table 1. All the surface soils are low in exchangeable sodium and tends to increase with depth and both are potentially considered as good productive soils. Under virgin conditions, the Waco black earth supports native pastures dominated by <u>Dicanthium sericeum</u> and <u>Panicum queenslandicum</u>, whereas the grey clay supports a brigalow forrest vegetation dominated by <u>Acacia harpophilla</u> and <u>Casuarina cristata</u>. The long term average annual rainfall for the two sites are 660 and 630 mm, respectively.

Table 1 : Some physical and chemical properties of the vertisols used.

Soil	Cult. history (years)	Clay content (%)	CEC	CCR	Org C (virgin soil) (%)
			(cmol kg^{-1})		
Waco	0 - 64	70.9-74.9	70.7-88.7	96-118	1.63
Langlands	0 - 49	53.4-56.8	39.8-43.9	70-79	3.04
Logie	2 - 39	39.5-47	30.4-38.0	77-91	3.04

Soil samples were collected from the 0 - 0.10 and 0.10 - 0.20 m depths using a 96 mm thin-walled sampler and three cores in close proximity were bulked. At each site, four bulk samples were collected from an area of 20 m2. The samples were broken gently by hand into 20 - 40 mm fragments and air-dried. A subsample was taken, ground and sieved to < 2 mm.

Soil structural stability was measured using the wet sieving and dispersion methods. Air-dried soil < 9.5 mm was wetted by immersion and wet sieving was carried out for 5 minutes at 40 strokes per minute. The results were expressed as mean weight diameters (MWD). Dispersion was carried out in one liter sedimentation cylinders with 50 grams of air-dry soil (<2 mm) immersed in water and made up to one liter. An air gap of 105 mm was maintained above the suspension. These cylinders were shaken end over end for 30 minutes at 20^{0}C and 20 rotations per minute. The contents of dispersed materials of <2 and <20 µm were determined by sampling with the pipette at the appropriate times calculated using Stoke's law, and dried at 105^{0}C. The results were expressed as a proportion of the potentially dispersible material or Dispersion Ratios for Clay (DRC) or Silt (DRS). When expressed as a proportion of the total soil, it was referred to as Dispersed Clay (D2) or Silt & Clay (D20).

Organic carbon contents were measured using the Leco dry combustion furnace. Exchangeable Sodium and other cations were measured using the method of Thomas (1982) and the Cation Exchange Capacity using the method of Rhoades (1982). Exchangeable sodium was expressed as either a percentage of the activity of the clay fraction (Exchangeable Sodium Percentage-ESP) or of the total soil used (Exchangeable Sodium content-ES). The soil hydraulic conductivity (K) was measured using a constant head permeameter. Air dry soil (<2 mm) was packed into the permeameter by immersion into water to ensure uniform slaking prior to commencement of measurements. In all cases, K was determined from the constant outflow rates between 7.5 and 8.5 hours after commencement.

RESULTS

The effect of period of continuous cultivation on the OrgC%, MWD and DRC of both soils are shown in figs 1, 2 and 3. Similar pattern of change were obtained for DRS, D2 and D20. OrgC% decreased with time, being more rapid on the Langlands than the Waco soils. The rates of decline in OrgC% were consistent with those measured on the same sites by Dalal (1982). MWD decreased rapidly over the first 20 years of cultivation and remained relatively constant thereafter at a level that was adequate to maintain a reasonable level of productivity. Similarly, DRC increased over the first 20 to 25 years on the Waco, but on the Langlands surface soil the pattern was not clear. In the .1 -.2 m depth, it continued to increase with time.

MWD were significantly correlated with all the dispersion parameters. Therefore, in principle any of these parameters would be suitable for describing the structural status of the soils. However, the dispersion parameters were better correlated to ESP and K than was MWD (Table 2). MWD and all dispersion parameters were well correlated to clay content. The increasing dispersion with period of cultivation on the Waco soil was associated with increasing ESP (fig 4).

Table 2 : Value and significance of correlation coefficients (r) between the structural parameters and other soil physical and chemical properties. *** indicates significance at $P<0.001$.

	MWD	DRC	DRS	D2	D20
Org C	.35***	-.48***	-.41***	-.39***	-.35***
Clay %	-.73***	.63***	.67***	.88***	.88***
ESP	n.s.	.62***	.52***	.46***	.41***
ES	-.58***	.79***	.74***	.88***	.81***
log K	.51***	-.67***	-.70***	-.75***	-.78***

DISCUSSION

A major effect of continuous cultivation was a reduction in the organic matter content of the soil, and therefore a reduction in the chemical fertility of the soil (Dalal and Clarke, 1984). This was also associated with a decline in structural stability, however, the poor correlation of OrgC% with the structural parameters indicates that organic matter content is not a major factor in stabilising soil aggregates. Structural stability in these soils are more strongly affected by their clay contents and the properties associated with the clay fraction as indicated by the correllation coefficients in table 2. Increasing levels of Exchangeable Sodium Percentages was the major reason for the increasing levels of dispersion with cultivation on the Waco, but no distinct patterns was observed on the Brigalow soils. The reason for the increasing sodium levels are not clear, but is probably associated with loss of topsoil due to erosion which exposed subsoil with higher sodium levels.

Figs 2 and 3 show that the wet sieving and the dispersion by the end over end methods are equally good for the qualitative description of the structural status of the soil. However, it would be advantageous to be able to predict other soil properties from measurement of soil structure or vice versa, and to eventually predict the physical behaviour of the soil from such measurements. From the data in table 2, it is obvious that MWD is inferior to the dispersion parameters for that purpose.

Table 2 also indicated that correllations between parameters expressed on the same basis (Dispersion Ratios vs ESP and Dispersed Contents vs ES) should be superior to those expressed on different bases (Dispersion Ratios vs ES and Dispersed Contents vs ESP). The best correllations were obtained between D2 and D20 with ES giving r values of .88 and .81 respectively. Fig 5 shows the relationship between D2 and ES for the three soils. D2 and D20 are also strongly correllated to clay content (Cl) and a stepwise regression analysis resulted in the following equations :

$$D2 = 0.001173{*}Cl + 0.0126{*}ES - 0.0213, \quad R^2=0.879 \quad [1]$$

$$D20 = 0.004410{*}Cl + 0.0282{*}ES - 0.0191, \quad R^2=0.819 \quad [2]$$

The soils hydraulic conductivity K was also best correllated with D2 and D20 and fig 6 shows the relationships between log K and D2. It should be noted here that the parameters ES, D2, D20 and K are all properties of the bulk soil and are not limited to the colloidal fraction only. Therefore, texture becomes important as shown by equations 1 and 2. Considering that the three soils investigated covers a range of clay contents (39 to 75%) representative of the vertisol order, these common relationships could well represents other members of that order. Work is currently underway to check this possibility.

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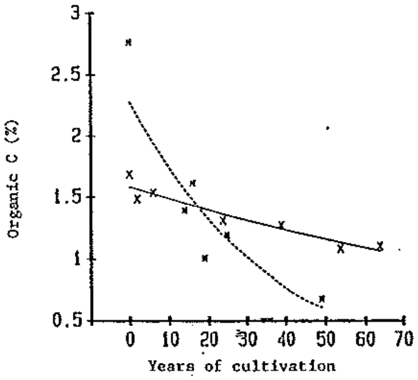

Fig. 1 Changes in Org. C content with period of cultivation for the Waco (x) and Langlands (*) soils.

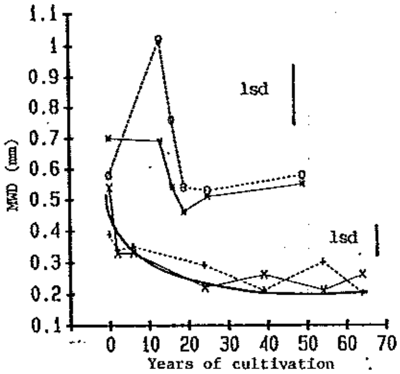

Fig. 2 Changes in MWD with period of cultivation for the Waco (x: 0-.1m and + :.1-.2m) and Langlands (*:0-.1m and O:.1-.2m) soils.

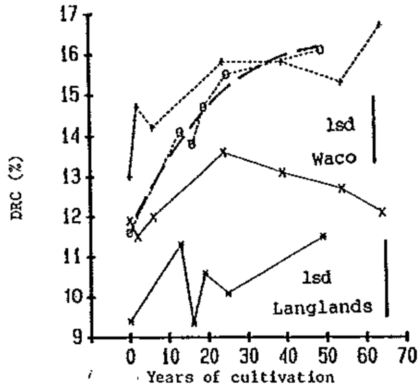

Fig.3 Changes in Dispersion Ratio for Clay with period of cultivation for the Waco and Langlands soils. Symbols are similar to Fig. 2.

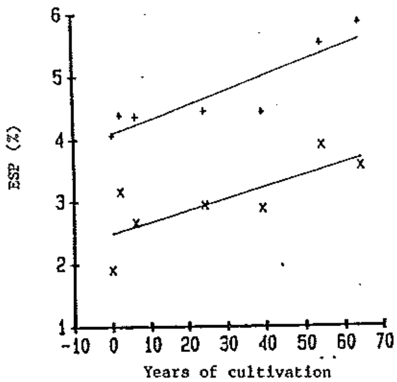

Fig. 4 Changes in Exchangeable Sodium Percentage (ESP) with period of cultivation for the Waco (x:0-.1m and + .1-.2m).

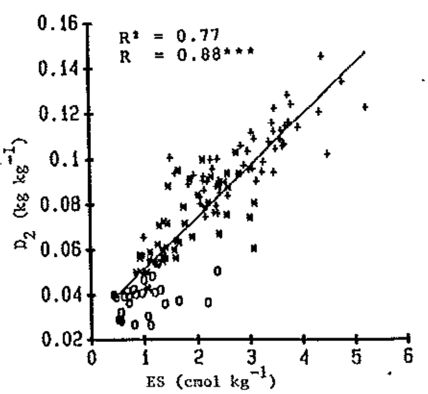

Fig. 5 Relationship between Dispersed Clay Content (D_2) and Exchangeable Sodium Content (ES) of the Waco (+), Langlands (*) and Logie (O) soils.

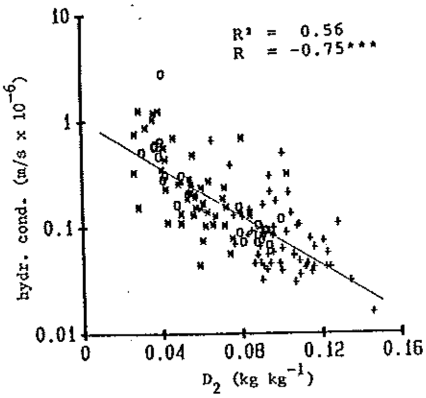

Fig. 6 Relationship between hydraulic conductivity and the dispersed clay content for the Waco (+), Langlands (*) and Logie (O) soils.

PENETRATION RESISTANCE ISOPLETHS FOR ASSESSMENT OF SOIL STRENGTH UNDER VARYING MANAGEMENT REGIMES

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ABSTRACT

Diagnostic techniques to evaluate cultural practice effectiveness for managing soil strengths are needed. A recording penetrometer used on a uniform grid of penetrations produced analog records (on 3 x 5 cards) of soil strength vs depth. These were used to develop profile contour plots of soil strength. Digitization was done using a flatbed plotter, programmed to aid in placement of the digitizing eyepiece. Contour depth, shape, and frequency of strength observations were used to compare tillage treatments. Methods of strength correction for soil water differences and other applications are discussed.

INTRODUCTION

High soil strengths (cone index or penetration resistance) resulting from tillage, traffic, or genetic pans inhibit root growth (Voorhees, 1987, Trouse, 1983) and limit root exploration for water and nutrients (Taylor et al., 1966; Gerard et al., 1982; Barley et al., 1965). Various management techniques prevent or eliminate high strength zones and maintain root pathways (Busscher et al., 1988, Campbell and Phene, 1977; Elkins and Hendrick, 1983; and Voorhees et al., 1978). Suitable diagnostic techniques are needed for evaluating cultural practice effectiveness. Cone tip penetrometers are commonly used to assess soil strength. The earliest penetrometers involved a simple proving ring that recorded only the maximum soil strength encountered for the depth of penetration. A new technique involves the recording penetrometer (Carter, 1967; Morrison and Bartek, 1987; Terry and Wilson, 1952). There are three types: handheld, manual, analogue; tractor-mounted, hydraulically driven, digitizing; and handheld, manual, digitizing.

Cost, portability, and field ruggedness make handheld types attractive. Tractor-mounted hydraulic types have the advantages of constant insertion rate and direct computer interface, enhancing precision and data reduction, but are costly, have limited field accessibility (e.g., in corn), and impose additional traffic. Strengths recorded using constant insertion rate probes and manual probes were compared by Morrison and Bartek (1987) who concluded their agreement was good. If care is taken to maintain reasonably uniform insertion rates, readings from manual units discriminate even subtle strength pattern differences (Busscher and Sojka, 1987; Busscher et al., 1986a). In non-agricultural studies, handheld types may be the only penetrometers portable to remote sites (Adams et al., 1982). Finally, the cost advantage of analogue over digitizing handheld types remains a factor, since analogue plots can be rapidly digitized with computer equipment already on hand at most research stations and have the potential for automated image analysis. The authors have developed a system of profile strength assessment with a commercial manual probe (Carter, 1967). This paper outlines and demonstrates the method using a comparison of fall vs spring-bedding.

METHODS AND THEORY

Irrigated Russet Burbank potatoes (Solanum tuberosum L.) were grown on a Greenleaf silt loam (fine-silty, mixed, mesic Xerollic Haplargids) which had been fall-bedded (FB) or bedded before spring planting (SB). Following planting, traffic was limited to a mid-season herbicide application. Soil strength was compared by determining profile strength contours shortly before harvest at two field locations (replications) for each treatment.

Strength assessment involved analogue recording of a grid of soil strengths by making penetrations at 11.4 cm intervals perpendicular to known sources of strength variation (e.g., planted rows, wheel ruts, etc.). Probing depths were to 60 cm (20 cm below the tillage) to reduce spurious reading effects three replicate probings spaced 10-12 cm apart, parallel to the strength variation for each position of measurement, were recorded on an index card as strength vs depth. No attempt to order the replicated probings was made. Each card was placed on a flatbed plotter, used as both a digitizer and an eyepiece controller, and digitized at 5 cm depth increments via a semi-automated process (Busscher et al., 1986b). The method is similar to those used with freely moving digitizers, but here the computer positions the eyepiece on the baseline, greatly accelerating digitization. A single operator can process up to 300 cards (12,000 digitized entries) per day, including automatically averaging the three separate tracings at each depth and recording the data electronically. After the last depth of each card was digitized, the baseline was redigitized. If the slope of the baseline was not zero when all points were entered, they were corrected for the change in strength due to the slope (tilting of the card). Cone indices were thus known for each intersection of a grid with intervals 5 cm deep by 11.4 cm wide. Isopleths were drawn from the matrix giving a penetration resistance contour map.

Log transformed cone indices (Cassel and Nelson, 1979) were statistically tested using both the general linear models procedure (GLM) and the regression procedure (REG) of SAS (SAS Institute, 1985). The GLM design used was Tillage, Rep., Tillage x Rep., Depth, Position, Depth x Tillage, and Position x Tillage, with depth and position considered covariants with the tillage variable. Since strength does not vary linearly with position, position squared was used in the GLM procedure.

A regression equation modeled strength vs soil depth and lateral position using the first four orders of the depth and position and the first and second order interaction terms. Regressions were performed for each treatment and for selected combinations of treatments that were compared. Significance among treatments was determined by calculating an F statistic from the respective error mean squares of the selected combinations and the appropriate individual treatments, using a 10% level of significance with the Bonferroni adjustment for multiple comparison procedures (Draper and Smith, 1966). The Bonferroni adjustment divides the significance by the number of comparisons. The $P < 0.10$ level of significance for 100 samples uses a 0.001 F table. Individual comparisons were not made if the treatments were not statistically different in the GLM table. The regression procedure simulates strength as a function of position and depth and compares the simulation of fit. If the simulations significantly describe the data, a simple F-statistic can be calculated from the error mean squares and degrees of freedom. The GLM and REG procedures used in this manner rejected the null hypothesis if either strengths were dissimilar or were distributed differently.

Gravimetric soil water contents (W) from regular depth intervals for all treatments and probing dates were statistically tested by analysis of variance at the 5% level using GLM. Correcting strengths for significant differences in W between probings permits examination of soil strength aspects other than those caused by W (Busscher, 1987). Perumpral (1987) examined various soil-water correction methods, and Bennie (1986) showed that cone index could be predicted as a function of moisture content and bulk density by:

$$\text{Log}\ (C) = a * \text{LOG}\ (B) + b * \text{LOG}\ (W) + \text{Log}\ (c) \qquad [1]$$

where C is cone index, B is bulk density, W is gravimetric water content and a, b, and c are soil dependent parameters. To correct cone indices of one treatment for differences in W between it and another treatment, the model takes the form:

$$C_1/C_2 = (W_1/W_2)^b \qquad [2]$$

RESULTS AND DISCUSSION

Researchers disagree about the precise limits of penetration resistance to root growth, which varies with species and soil properties (Taylor et al., 1966; Camp and Lund, 1968; Campbell et al., 1974, and Gerard et al., 1982). Most literature indicates that 2.0 MPa as measured by a 5-mm flat-tipped penetrometer is a limit. This corresponded to 2.5 to 3.0 MPa for a 13-mm diameter 30 degree cone-tipped recording penetrometer (Busscher et al. 1986a). Once the critical penetration resistance is established, relative profile soil strengths can be evaluated. Figure 1 shows the soil strength contours of SB and FB treatments at field water contents (a and b, respectively) and FB corrected to the SB field water content (CB) in Figure 1c. It is apparent that the uncorrected strengths of the FB treatment (Fig. 1b) result in part from a drier profile, because upon correction, contours change depth and shape (Fig. 1c). Mean strengths for SB, FB, and CB were 3.82, 2.18 and 2.34 MPa, respectively. Spring Bedding (SB) was significantly different from FB and CB. Depth to the 1 MPa strength contour in Figure 1a is well above 0.2m but in 1c is well below 0.2m. Similarly the 3.0 and 4.0 MPa isopleths are deeper in Figure 1c. Since there is no intervening shallower high strength zone this indicates a more favorable rooting volume for FB as profile W varies. A zone of traffic-related compaction is identifiable in SB as the lobes of 2.0 MPa and 3.0MPa strength centered under the trafficked inter-row in Figure 1a. The frequency distribution of strength (Figure 2) verifies that FB should favor rooting since low strengths occur more frequently in the FB and CB treatments observed.

There are various approaches to correction for W. Asady, Hook, and Threadgill (1987) considered the water effects separately as a covariate. Busscher (1987) compared equations that corrected C in flat-tipped penetrometers for differences in W among treatments. One of the better equations solved a boundary value problem to obtain a sigmoid relationship between C and W. Here C was a function of Secant(π/2*(W/SAT-1)-1) where SAT is the porosity of the soil. Recently Busscher and Sojka (1988) scaled profile cone indices from 0 to 1 to provide patterns of relative strength. This permitted comparison of cone indices with W differences without correction.

Other strength evaluation approaches (not shown) include determining mean depth to critical penetration resistance, taking the simple mean of profile strength readings, or finding the mean profile cross-sectional areas between given strength limits. Since water and nutrient availability depend on the volume of rootable soil it is useful to compare the cross-sectional areas of soil below a given penetration resistance, provided shallow high-strength layers do not overlie non-limiting layers which, though inaccessible by roots, would increase calculated rootable volume. Each approach has validity and can be used with crop data to determine strength-dependent relationships via regression analysis. An example of this approach would be the regression of yield on the area of profile below the critical soil strength.

CONCLUSION

Determination of soil penetration resistance isopleths provides an effective means of evaluating effectiveness of cultural practices for managing soil strength.

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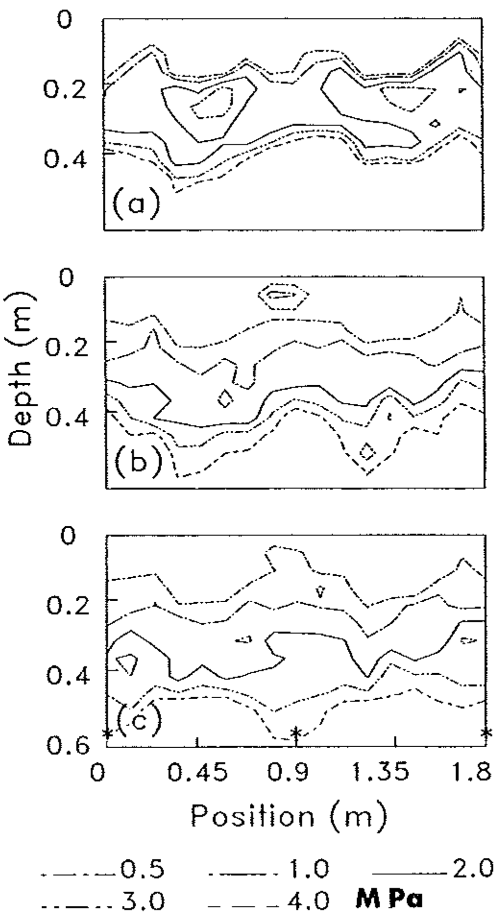
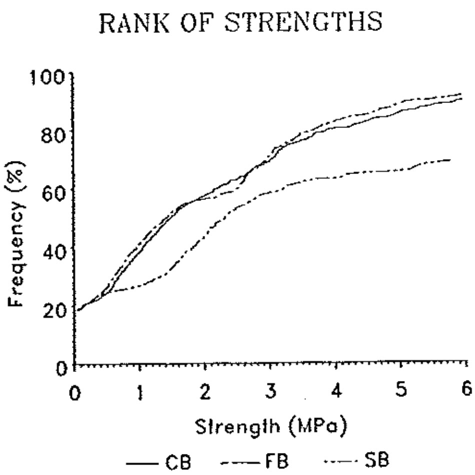


Figure 1.--Soil isostrength contours of (a) spring bedded, SB, at field water content (b) fall bedded, FB, at field water content and (c) fall bedded corrected to the water content distribution of the spring bedded treatment, CB. Contour lines are in MPa. Asterisks are row locations.

Figure 2.--Distribution of strength values for fall bedded, and spring bedded data at field water contents and for fall bedded data corrected to the water content distribution of the spring bedded treatment.



SEEDBED STRUCTURE AND SEEDLING EMERGENCE OF MAIZE

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ABSTRACT

Seedling emergence can be widely affected by mechanical impedance of the surface layer, soil environmental factors and climatic factors. In order to ensure the required level of seedling emergence, one of the main purpose of tillage systems is to obtain a favorable seedbed structure. In laboratory we study the maize seedlings emergence as related to soil crusting. We measure the emergence force of the coleoptile and study its behaviour with different physical and mechanical properties of crusts.

INTRODUCTION

Seedling emergence is inhibited largely by the occurence of surface soil crusts that can form naturally in some soils due to weather conditions. Several works carried out the force determination of : legumes, cotton, maize. Some authors studied the different processes and properties of crusting in field or in laboratory and other scientists are interested in seeking the relations between emergence and properties of crusts (RATHORE et al., 1981 ; GOYAL and DREW, 1982 ; BERKMAN, 1985).

To perfect germination and stand models which predict percentage and kinetics of emergence, we must better know the relations between characteristics of seedling and characteristics of mechanical obstacles.

In this work, we study the seedling behaviour when it must overcome obstacles of known mechanical and physical properties. Growth force and growth rate of coleoptiles are measured with a simple technique ; moreover the effect of surface obstacles is studied by utilizing artificial crusts mechanically bound with underlying layer.

MATERIALS AND METHODS

Plant material and force measurements

The force measurements and the emergence study are made on plants the coleoptiles of which are 5 to 25.10^{-3} m long. The coleoptile is put in a glass tube and its tip touches the steel plate (with two simple supports). A strain gauge glued on the beam indicates the deformation and allows with the elastic theory and calibration, the determination of the force and the rate (SOUTY, 1987).

Preparation of artificial crusts and determination of their characteristics

The experiments were carried out on three soils (Table I). We have perfected in laboratory the crusting formation to obtain homogeneous and reproducible material from a paste carefully put into paper rings of different height (2, 3, 8.10^{-3} m) and these disks dry until selected water content in a climatic compartment (20°C + 0,5°C).

The physical properties were determined : the thickness e measured in five points and the water content calculated at the beginning and at the end of experiments.

The resistance to penetration is measured by penetration of crusts by a cylindrical tip moved at an invariable rate. The maximum force used to break the crust is therefore determined.

TABLE I - Particle size distribution

%	1	2	3
clay (< 2 µm)	10.0	32.1	52.8
fine silt (2-20µm)	19.4	37.4	30.8
coarse silt (20-50µm)	32.3	15.7	6.3
fine sand (50-200µm)	22.7	13.4	7.9
coarse sand	15.6	14.0	2.2
organic matter	0.44	1.63	2.42

Emergence study

The figure 1 shows the device utilised for emergence study. The containers with seedling, crust and ring are put away in the climatic compartment and we observe the emergence.

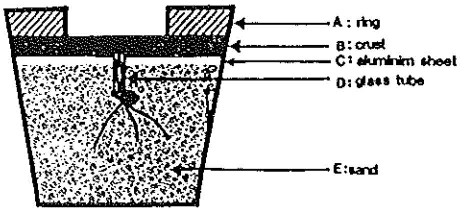

Fig. 1. Device for emergence study

RESULTS

Characteristics of coleoptiles

The laboratory tests with steel plates of different coefficient K (bending resistance) show that :

(i) the growth force seems independant of the K value and of the initial length of the coleoptile (5 to 25.10^{-3} m). The corresponding pressure varies about 50 KPa to 300 KPa (Fig. 2).

(ii) but it seems lower without putting the coleoptile in glass tube (inferior to 150 KPa).

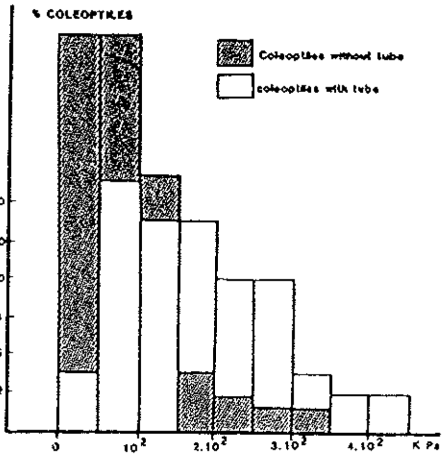

Fig. 2. Pressure exerted by coleoptiles

(iii) the growth rate is very influenced by the K value and varies inversely with it (Fig. 3).

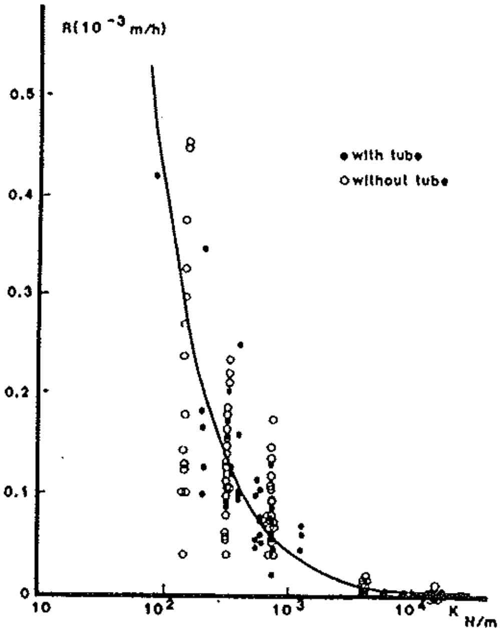

Fig. 3. Growth rate versus K value

Characteristics of crusts

The force F needed to break or hole the crust has been measured on check crusts. Its value strongly depends on the granulometry, the thickness e and the moisture content W. But for a soil, the ratio F/e^2 (the same as the modulus of rupture) is only function of the moisture content (Fig. 4).

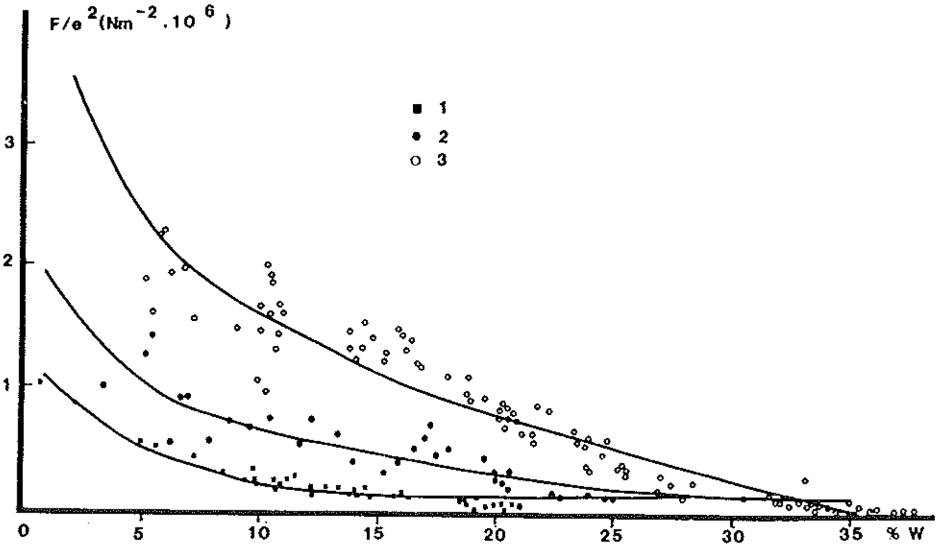

Fig. 4. Variation of F/e^2 with water content

Emergence of seedling

The emergence percentage has been determined in some situations (Fig. 5) and on the three samples of soils we establish a low threshold of moisture content whose value varies with the granulometry and the thickness. We observe, for a same thickness, with an increasing clay percent, a rising threshold.

DISCUSSION

The results show that thickness and water content are the most important factors which are easily appreciated. For silt soil (Collias) a 15 % to 20 % moisture is necessary to emergence at any thickness. But for the two other soils the limit moisture content increased with clay content and thickness. The emergence process through soil crusts is mechanically different according to the properties of surface obstacles and not always well explained. There is a puncturing action in plastic medium or a breaking action in dryer medium. If we assume that crust is a circular plate fixed at the periphery (TIMOSHENKO and WOINOWSKY-KRIEGER, 1961), the experiments with the cylindrical metallic tip allow to estimate the maximum tensile stress at the upper surface for breaking the crust (function of F/e^2) and therefore to calculate the needed force when the coleoptile bends the crust. We can compare this force value for the coleoptile force previously determined ; if it is lower, the seedling will emerge through the soil crust. We notice that this condition is only obtained for coleoptiles with every crust of soil 1.

In the clay soils (2 and 3) the mechanical process is undoubtely more complex than a flexion alone.

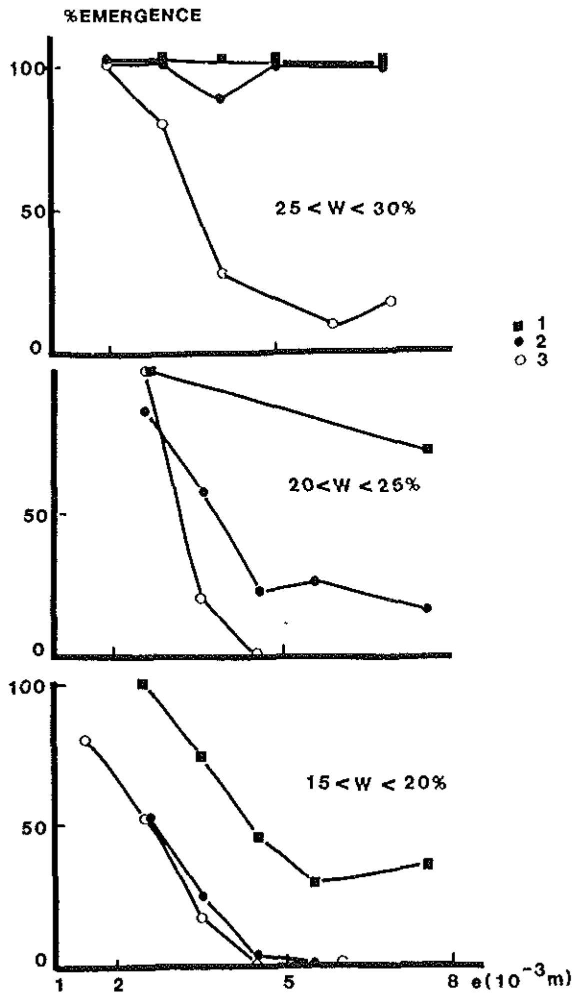

Fig. 5. Emergence percentage

CONCLUSIONS

1. The maize coleoptile is a check tool for crusts penetration. Another seedling such as cotton, soja whose force is bigger, would move the limit characteristics of crusts permitting emergence.

2. In all the cases these limit values are function of thickness and moisture content.

3. Under silt soil crusts, it seems that the emergence occurs by a flexion giving a traction stress at the upper surface.

ACKNOWLEDGEMENTS

We are grateful to Colette RODE for her valuable technical participation in all these experiments.

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SEEDBED CHARACTERISATION BY VIDEO IMAGE ANALYSIS

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ABSTRACT

In order to optimise conditions for germination and emergence, seedbed structure has to be controlled. Structure has usually been characterised by aggregate size distribution determined after production of the seedbed by manual surface profilometer methods or by sieving. An alternative method is the use of video image analysis which can continuously assess the seedbed as it is prepared. Automatic control of seedbed preparation to cope with varying soil conditions is then possible.

Algorithms have been developed for analysing a video image and have been tested on a range of seedbeds. Although further evaluation is required, a simplified line scan system to capture and analyse line transect information shows promise as a viable system.

INTRODUCTION

The surface topography of cultivated soils is an important characteristic in assessing the effectiveness of cultivation operations, whether for primary tillage or for seedbed preparation. It is also important in considerations of soil erosion and water run-off processes. The surface roughness, or micro-relief, of a seedbed relates to its structure and aggregate distribution and influences planting operations and crop emergence. There have been various attempts, reported in the literature, to relate a measure of surface topography to such factors as the effect of rainfall and erosion resistance.

The nature of soil surface topography is essentially random with a superimposed periodicity due to such factors as cultivation implement width and direction of working. An early attempt to quantify roughness was made by Kuipers (1957), who defined a roughness index as the logarithm of the standard deviation of micro-relief surface heights. Dexter (1977) considered power spectral density and auto correlation functions of transects across a soil surface, but concluded that Kuipers' measure of roughness was superior. Romkens and Wang (1986) proposed the use of a roughness parameter defined as the product of the micro relief index and the peak frequency as derived from a transect through the surface topography. The index was essentially the area between the measured surface profile and a mean line through the profile, and the frequency was the number of crossings of the mean line through the profile. Destain and Verbrugge (1987) determined power spectral density and auto correlation functions for two different soil tillage operations for seedbed preparation. They concluded that a useful characteristic could be determined from the correlation function by taking the slope of a straight line fitted through correlation values between lags of 0 and 10 mm.

Various methods have been used to measure soil roughness, but most have been based around pin profilometers and are therefore contact devices. The means of reading out the profile from the profilometer have varied from photographic to direct measurement of pin elevation to the use of LVDT displacement transducers and hall switches. Profilometers have been reviewed by Zobeck and Onstad (1986). Non contact optical probes have been described by Harral and Cove (1982) and Destain and Verbrugge (1987).

Because of spatial variations in factors such as soil type, original condition and moisture content, seedbed preparation equipment produces variable results across a field. If seedbed condition is continuously monitored by assessing surface roughness, automatic control of the seedbed equipment may be implemented to optimise seedbed condition. Such a system would require the mounting of non-contact surface roughness sensors on the field equipment. An optical method such as developed by Harral and Cove (1982) may be suitable, although soil reflectance causes problems. In this paper, a totally different non-contact method, video image analysis (VIA), is considered and is shown to have potential for surface roughness assessment.

VIDEO IMAGE ANALYSIS

In essence, a picture of the soil surface is regularly captured by a video camera, stored in a framestore, and operated upon by various software algorithms to produce a quantitative assessment of surface roughness. There is, thus, a fundamental difference between the information obtained from VIA and that obtained from a conventional profilometer. A profilometer measures the heights of the surface texture on a transect about an arbitrary reference level. A series of closely spaced parallel transects may be analysed to yield information on the surface topography. With VIA, the visual contrast in a picture of the soil surface is analysed. Thus, essentially, peaks are distinguished from valleys and information can be obtained on the size and periodicity of high features, i.e. of aggregates and clods in the surface. Different features can be emphasised by the use of structured artificial light, or the surface may be viewed in diffuse ambient conditions. A typical video image may consist of 512 x 512 = 262,144 pixels or picture elements, with each pixel indicating one of 64 different gray levels. Thus the amount of information to be processed is very great and, until recent years, computing speeds have been insufficient. However, the decreasing cost and increasing processor speed of VIA equipment has made its application to surface roughness assessment viable. A simpler form of VIA, the use of a line scan camera yielding a line transect of gray levels, is also considered in this paper.

METHODS

Analysis equipment

The VIA equipment consisted of a camera mounted on a vertical stand to view large photographs of seedbeds and a framestore and analysis card based on a VME bus. The video image was displayed on a monitor and the analysis equipment was controlled by a keyboard and terminal. The equipment included 2 3½" floppy disc stores and a 20 megabyte Winchester store which could hold up to

70 frames. The Forth language was used for programming the analysis algorithms into the system. A video frame consisted of 512 x 512 pixels with a resolution of 256 gray levels per pixel. With the size of photograph and camera optics used in the initial tests, one pixel represented between 2 and 4 mm on the ground.

Development of algorithms

A number of algorithms were developed to manipulate the image, display it in various ways and extract quantitative information. The scene viewed by the camera was displayed on the monitor and then stored. The monitor screen was then split into 4 quadrants with the original scene displayed in 1 quadrant and the other 3 used for displaying the results of analysing the image. A histogram of gray levels of all pixels in the image could be displayed in 1 quadrant. In order to compensate for changes in ambient light and normalise lighting in different images, the contrast range of an image could be 'stretched' over the full range (1-256) available and the image redisplayed.

In order to identify surface features, a binary image was formed by defining a threshold gray level and turning off all pixels (i.e. make 'black') below the threshold and turning on (i.e. make 'white') all pixels above. A procedure was then used to search for changes from black to white, indicating the edge of a feature and then following the edge to identify and size the feature. Equivalent diameters and areas were then determined.

Length calibration of the video image was achieved by placing a marker strip of alternate black and white strips on the seedbed at the edge of the viewing area of the camera. The analysis system identified the strips and automatically determined calibration in terms of pixels/mm.

Line transect analysis

A procedure was developed for determining a profile of gray levels on any specified transect through the image area viewed by the camera. A marker line on the monitor screen could be moved up and down from the keyboard to identify the required transect and a gray level profile then displayed. This line transect information was then downloaded to another computer where random signal analysis was undertaken on the data. Power spectral density and auto correlation functions were determined.

RESULTS

In order to carry out an initial assessment of VIA as a technique for characterising seedbed surface roughness, photographs were taken of 9 different seedbeds. Several areas of at least 500 x 500 mm were photographed from a position vertically above the image area using natural lighting. On each occasion, there was cloud cover resulting in diffused lighting with no shadows cast. 300 x 300 mm black and white prints were produced from the negatives and used for viewing by the video camera. The seedbeds were visually assessed by 3 people on a scale of 1 (poor) to 10 (good) as shown in Table 1.

Photographs of all the seedbeds were subjected to VIA using a threshold gray level of 160. Examples of binary images from a good and a poor seedbed are shown in Figs. 1 and 2.

Gray level profiles from line transects were obtained at 4 positions equally spaced across each seedbed image. Power spectral density curves and auto correlation functions were computed for each transect. Examples from the same two seedbeds are shown in Figs. 3, 4, 5 and 6 respectively.

DISCUSSION

For application to control of field operations, the sensing system must supply condensed quantitative data that correlates with operator assessment. Thus, arbitrary numbers are sufficient provided that they correlate with roughness. Characterising surface topography by one or two parameters is difficult. A number of routes were explored for extracting one or two parameter characteristics from the two-dimensional image information and from the transect gray level information, and these are tabulated in Table 1.

Table 1. Seedbed parameters

Ref No.	Mean assessment	Clod count/m^2	Mean line crossing/m	A	B	C
02B	8.7	5250	125.8	0.09	–	2.55
03A	8.7	5420	104.8	0.10	14.4	3.89
10B	8.7	2940	89.8	0.10	14.3	4.89
05A	7.3	2060	69.0	0.06	45.0	11.48
08A	7.0	2340	71.3	0.08	46.5	6.52
01D	5.7	2590	80.8	0.10	14.0	4.86
07C	5.3	2450	65.5	0.07	165.0	10.13
06A	3.0	1700	54.3	0.07	27.7	7.72
09C	3.0	1690	58.3	0.07	49.5	7.27

Total identified clod counts and the number of times the profile crossed the mean line through the profile are listed in Table 1. The power spectral density curves contained a number of peaks but one or two characteristic frequencies were not identified. The correlation functions were characterised in two ways. The one suggested by Destain and Verbrugge (1987) is listed in column A. Secondly, a decaying exponential curve was fitted to the correlation functions from zero lag to the point at which the slope of the function first changed from negative to positive. The intercept of this curve with the lag axis is listed in column B. The area between the curve and the lag axis up to the slope change is also listed in column C.

As with operator assessment of seedbed condition, there is a subjective element in video image analysis. This centres around the threshold contrast level set to derive a binary image of the picture. The analyses described in this paper were based around a threshold level of 160. The effect of reducing the threshold to 140 was to reduce the number of clods identified by 25-30% As there is a subjective element in assessing seedbeds, an alternative to quantitative assessment is the use of self learning algorithms. A number of seedbed images are presented to the image analysis system, together with a merit figure for each seedbed. The algorithms effectively "learn" what constitutes a good seedbed and provide increasingly accurate assessment as the number of seedbed images presented to the system is increased. In essence, this is implementing an expert system to assess the seedbed.

The feasibility of using video image analysis for continuous assessment of seedbeds requires further evaluation, but the results of the present study are promising. The practical implementation of a system is at present limited by the cost and processing time of current analysis systems. However, the present results (mean line crossings in Table 1) indicate that a series of line transects may be sufficient to characterise seedbeds. The use of a line scan camera and the processing of much less data will be cheaper and faster than full VIA. Further studies then need to be undertaken into the effect of speed of movement of the field machinery on image capture, the effect of artificial illumination, and the further characterisation of line transects, together with the implementation of a line scan system.

CONCLUSIONS

1. The potential of VIA for assessing surface roughness of seedbeds has been studied.

2. VIA has potential as the sensing system in the control of tillage equipment to produce more uniform soil conditions.

3. The subjective element in video image analysis may necessitate the use of self learning algorithms.

4. A line scan system would be preferred to a 2-dimensional image system because of the reduced cost and the greater ease of abstracting quantitative characteristics.

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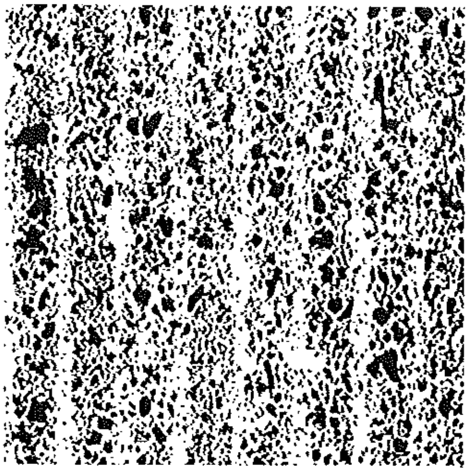

Fig 1 Good seedbed

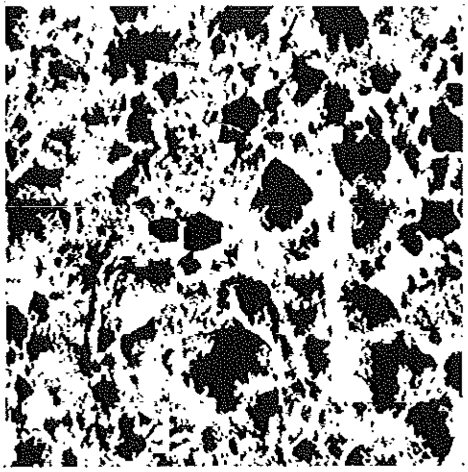

Fig 2 Poor seedbed

100 mm

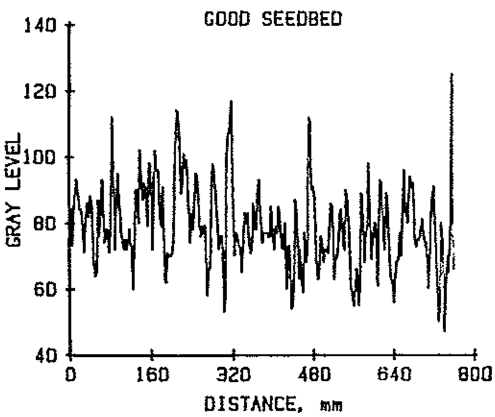

Fig 3

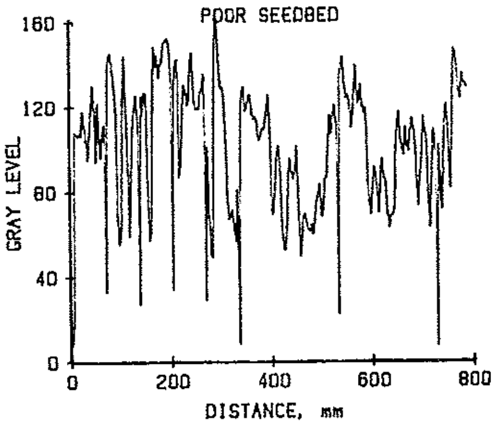

Fig 4

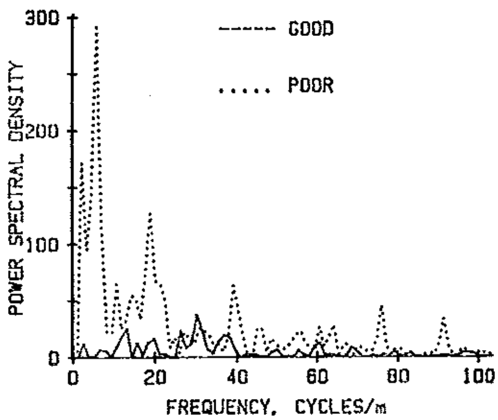

Fig 5

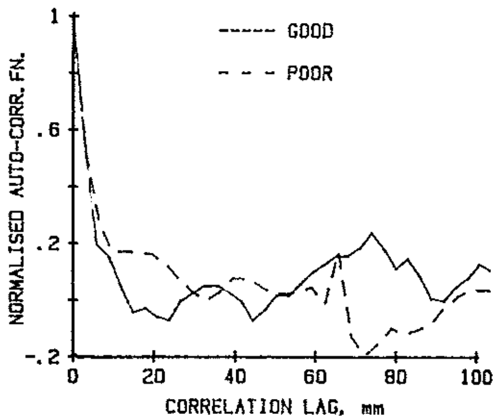

Fig 6

CRACKS FORMATION DURING SWELLING : EFFECTS ON SOIL STRUCTURE REGENERATION AFTER COMPACTION

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ABSTRACT

A laboratory study of the specific effects of wetting on cracking process is presented. Results show that an important quantity of cracks can develop during wetting, depending on : swelling properties of the soil material, initial water-content and effective swelling magnitude. It appears that division of coarse compact structural units into thinner ones, induced by rain or irrigation, can be important for soil structure regeneration after compaction and is not necessary limited to heavy clay soils.

INTRODUCTION

Quantitative assessment of soil degradation must take into account intensity and duration of compaction effects on soil physical properties and structure. Duration depends on structure evolution processes induced by human activity (soil-tillage) and natural factors. Among these natural factors biological and physical ones have to be considered. Main physical factors are water-content changes and frost. In mediterranean and tropical regions, where soil freezing is reduced or absolutely non-existent, water-content changes can have a big magnitude and high speed, and cracks formation induced by shrinkage and swelling is the dominating process of structure regeneration.

Previous works have intended to describe or model cracks development during the drying stage in both field and laboratory conditions (RAATS, 1984 ; HALLAIRE, 1987). In most cases no attention was paid to a specific effect of wetting on cracks genesis. Contribution of wetting was implicitly reduced to a purely passive phase of the process, except in the case of heavy clay soils in which compression due to swelling can cause shearing (BLOCKUIS, 1982). Apart from this mechanism, field observations (STENGEL and BOURLET, 1987) and analysis of water-content gradients mechanical effects, lead to the hypothesis that wetting of an initially dry soil volume could induce cracking, provided that pore space surrounding structural units was sufficient to allow free swelling. In this paper results of a laboratory study of cracks development during swelling is presented.

MATERIALS and METHODS

Materials and samples preparation

Three different soil materials, collected in tilled horizon, were compared. Analytical data are presented in Table I. Samples were air dried, ground and sieved on a 2 mm sieve. Sieved material was then mixed with water, the quantity of which was calculated to rise water-content up to liquid-limit value. The mixture was mechanically agitated in order to get a smooth paste, without any visible aggregate. The paste was poured into cylindrical tubes, 10 cm in diameter, and deposited on a dry sieved material layer to extract part of the water. Four weeks after, cores were picked out and cut in three slices. Water-content and bulk density were measured on upper and lower slices to control homogeneity. The central one, 3 cm thick, was kept for the experiment. It was put to dry in slowly evaporative conditions. Evaporation was stopped when the required water-content was obtained. The samples were then placed in an hermetic box for 48 hours. At the end of this process water-content was homogeneous, and no cracks could be detected neither visually, nor mechanically, nor by bulk density measurements.

TABLE I. Analytical data of soil materials

Textural Class	Particle size distribution (%)					Organic C (%)	CEC (meq/100 g)
	< 2 μm	2 - 20 μm	20 - 50 μm	50 - 200 μm	200 - 2000 μm		
Clay (C)	52.9	34.0	6.1	5.6	1.4	1.25	22.6
Silty-Clay Loam (SCL)	29.5	29.2	35.6	6.1	1.6	0.94	16.9
Silt-Loam (SL)	11.4	29.5	45.9	10.2	3.0	0.81	5.7

Wetting device and measurements

Wetting device is described in figure 1. The cores were placed on a saturated coarse-sand layer in order to avoid limitations in hydraulic conductivity. Water depression could be imposed by lowering water level down to -5 KPa without air entry in the sand bed. Duration of wetting varied between 3 and 30 days until an apparent equilibrium was reached. Cracks development was quantified by taking photographies of the upper section of the cylindrial samples during wetting. Photographies were used to measure cracks length per unit area, cracks width distribution and cracks porosity on an image analyser. Swelling curves of the different materials were determined by measuring water-content and bulk-density of cubic samples, approximately 1 cm^3 in volume. They were prepared as described previously and rewetted in different equilibrium devices, according to the required water potential values. In these wetting conditions no crack developped.

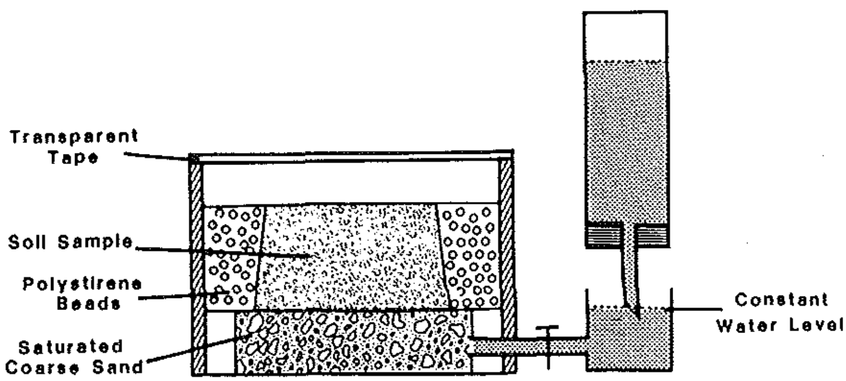

Fig. 1. Wetting device

RESULTS

Swelling properties

Relationships between void-ratio and water-content for the three materials are presented in figure 2. The three curves are quite different and representative of the main types which can be found with natural soil aggregates (STENGEL, 1982). For every material no significant effect of initial water-content of the samples which were rewetted on the swelling curve could be detected.

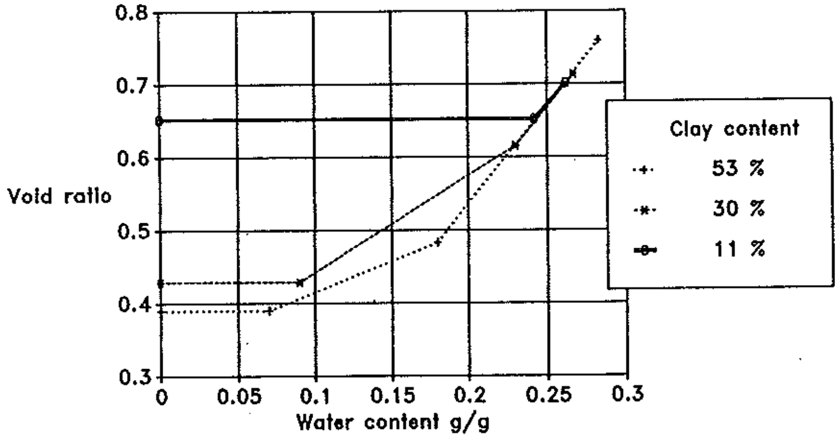

Fig. 2. Swelling-curves of different soil-materials

Cracks development

Cracks development during wetting occured with every soil-material. Final cracks-length per unit area (Lf), as determined at equilibrium with zero potential water, was much influenced by initial water-content Wi (fig. 3). For 53 % and 30 % clay materials, Lf decreased sharply from initial air-dry state to

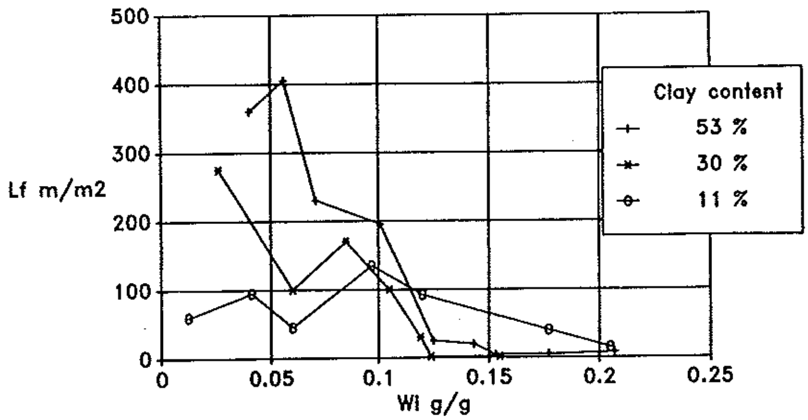

Fig. 3. Influence of initial water-content Wi on Lf, at equilibrium with zero-potential water.

a limit initial water-content. In these cases, cracking started before any change in water-content could be detected on the upper cylinder surface. With the silt-loam material (11 % clay), cracking started only when water-content reached saturation and swelling affected the whole samples (Fig. 2). Influence of Wi is less pronounced in this case in agreement with the hypothesis that crack developed only when the samples were wet (Fig. 3).

Porosity measurements (Table II) show that an important cracks-volume can be created by wetting. Note that these results are strongly dependent on confining mechanical conditions of our particular device. Importance of structural effect is better described by Lf variable. The highest Lf values vor the 53 % clay material (400 $m.m^{-2}$), are equivalent to an aggregate size of approximately 5 mm.

TABLE II. Cracks porosity of initially air-dried samples

Material Texture	C	SCL	SL
Initial Water-content $g.g^{-1}$	0.040	0.026	0.012
Cracks Porosity %	12.7	9.2	1.7

Cracks-length was related to swelling magnitude of the samples, as estimated from swelling-curves and water-contents, i.e. without taking into account cracks-volume (Fig. 4). Relationships between swelling and Lf are different for every soil material. Nevertheless comparing the initially dryest states of the different materials, Lf increases with swelling in agreement with the correlation which is generally accepted between swelling properties and cracking intensity.

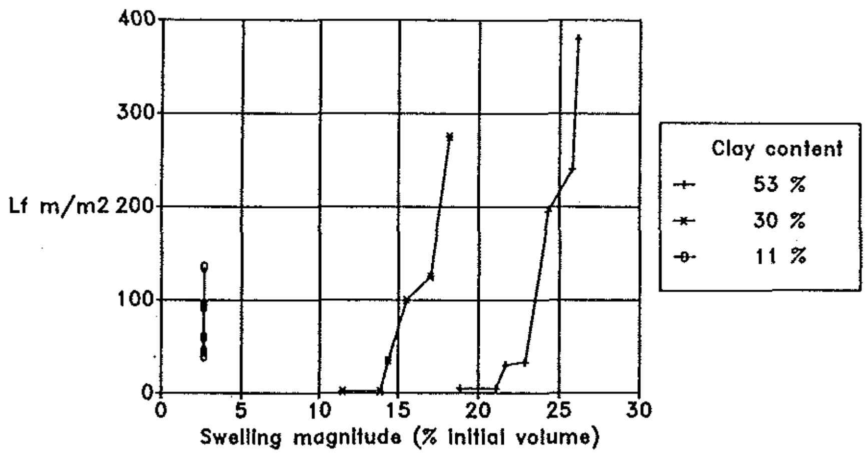

Fig. 4. Influence of swelling-magnitude, as induced by initial water-content, on Lf at equilibrium with zero-potential water.

Different water suctions were applied in the wetting device to 53 % clay material, initially air-dried samples. Lf decreased strongly with limited suctions values of 1 and 2 KPa (Table III). This result can be partly explained by the effect of wetting water potential on swelling magnitude.

TABLE III. Influence of equilibrium potential value on cracks-length (Clay-content : 53 %. Initial air-dried state).

Water Potential (KPa)	0	-0.2	-1	-2
Swelling-magnitude (% initial volume)	26.1	24.5	23.5	22.0
Cracks-length ($m.m^{-2}$)	360	430	155	80

DISCUSSION

Results show that cracking during the wetting stages of water-content variations can be important for soil structure evolution, even in low clay-content materials. Conditions which are required for cracks development into swelling materials can be deduced from experimental data obtained with the highest clay-contents. Non-cracked soil volumes must have an initial water-content inferior to the limit which appears on figure 3, and be in contact with a high potential source of water (Table III). Furthermore, a general requisite is that sufficient volume of pores exists between structural elements to ensure steric possibility of swelling and cracking. Such conditions can be fulfilled near the soil surface, in tilled layers, if the infiltration rate into compact clods is inferior to rain intensity. They can also be encountered near cracks walls during water infiltration into deeper horizons, after a dry period.

Cracks development due to swelling would then appear as an efficient process of structure regeneration after compaction by contributing to divide coarse structural elements, created by shrinkage or soil-tillage, into thinner ones. Field experiments, not reported here, were conducted on the clay soil to confirm this assumption (STENGEL and BOURLET, 1987 ; SIGALA, 1987). Cracking of a no tilled compacted layer, and cracking of compacted clods after tillage were described. Results were in good agreement with laboratory experiments : cracks development was observed during irrigation of initially dry soil.

Quantitative model assessment of cracks development probability appears rather difficult, because of difficulties in modelling water-movement in coarse structured layers. Cracks development during wetting makes it more complicated. In our experimental conditions, influence of cracking on water-movement was very important (STENGEL and BOURLET, 1987). Cracks which appeared in front of the wet zone of the samples acted as preferential pathways due to water capillary rise inside it. This phenomenon strongly influenced water uptake kinetics and contributed to progressive cracking of the whole sample volume. A very heterogeneous distribution of water-content was induced which makes very difficult to model water transfers.

CONCLUSIONS

(1) Laboratory studies with remoulded, homogeneous samples show that cracking can occur during wetting of materials having some swelling ability.
(2) This cracking process can generate an important quantity of cracks in terms of length per unit area or its three dimensional equivalent, area per unit volume. As a consequence division of non-cracked volumes in thinner structural elements can be expected.
(3) Cracks length which develops during wetting depends on swelling properties of the soil material and swelling magnitude as determined by initial and final water content or potential.
(4) Field studies on a clay soil corroborate laboratory results and demonstrate the importance of swelling cracks formation for structure regeneration after compaction.

ACKNOWLEDGEMENT.

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EFFECT OF THE STRUCTURE OF THE PLOUGHED LAYER ON THE SPATIAL DISTRIBUTION OF ROOT DENSITY

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INTRODUCTION

The distance that water has to travel from each point of the soil to the nearest root is an important parameter for modelling the water uptake by plants. It depends on the root length per unit area, but also on the spatial distribution of root length in the soil (Tardieu 1988a and b). The vertical distribution of the root length per unit volume (Lv), and the effect of the soil structure on this distribution have been studied by several authors, but few attempts have been done to study the spatial arrangement of roots in each soil layer. The objective of this article is to summarize the work done at Grignon on the effect of the soil structure on the three-dimensional distribution of Lv.

MATERIALS AND METHODS

A trial was carried out at Grignon (near Paris) from 1982 to 1987 in a clay-loam field. Four types of soil structure were reproduced in the ploughed layer, with three replications : 0 (individual small clods and fine earth), B (juxtaposition of compact decimeter-sized clods and centimetre-sized voids), C (ploughed layer uniformly compact down to the 30 cm depth), and A (50 cm-broad wheel compaction down to the 30 cm depth in one inter-row out of two, the remaining parts of the ploughed layer being similar to that in 0). These soil structures represent typical structures often observed at field ; the techniques for obtaining them are presented elsewhere (Tardieu & Manichon 1987a, Tardieu 1988a). They were characterized by a structural mapping of the ploughed layer (Manichon 1987), which consists of a zonation of vertical profiles, based on the visible porosity of clods and on their spatial arrangement. This mapping showed that the 4 typical structures considered were obtained each year Tardieu & Manichon 1987a, Tardieu 1988a). Soil bulk density was measured with a gamma-ray probe. In the ploughed layer (0-30 cm), average bulk density in C and in the compacted inter-rows in A was 1.65, differences between years being non-significant. In 0 and in the non-compacted parts of A, the density ranged between 1.35 and 1.45. A similar average density per layer was observed in B, but it corresponded to a different spatial distribution of the porosity : the dm-sized clods had a density of 1.7 to 1.8, but were separated by cm-sized voids. In the non-tilled layers, soil bulk density was not significantly different between treatments and visible porosity had the same structure. During the season, shrinkage cracks appeared in the compacted zone of the ploughed layer in A, and in C. They were not observed in the other treatments.

Maize (Zea mays L. early F1 hybrid LG1) was sown each year during the first week of May, with a plant density of 87000 ha^{-1}. In 1985, broad bean (Vicia faba minor cv Soravi) was sown on 9 March with a density of 60.000 ha^{-1}. Soil water content was monitored throughout the season using neutron probe and gravimetric measurements. The root system was observed 10 days after flowering. Root contacts were mapped on a vertical plane and on six superposed horizontal planes, which intersected the rooting volume of a sample area of 40 x 80 cm (Tardieu & Manichon 1986b). Root maps, drawn on transparent plastic sheets, were digitized with a 1 cm (2 cm in 1982 and 1983) grid mesh, using a binary code. Spatial arrangement of roots was studied (i) using statistical tests : autocorrelation and mean/variance ratio (Tardieu & Manichon 1986b), (ii) by superimposing structural maps on root maps, and calculating the root contact density for each structural zone, (iii) by computing the distance between each point of the plane and the nearest root (Tardieu 1988b). For each square of the map, we calculated the distance between the centre of gravity of this square and the centre of gravity of the nearest square where root contact was present (Fig. 1). This allowed to calculate the cumulative frequency distribution of distances between each point on the plane and the nearest root (Tardieu 1988b). In 1985 and 1987, root lengths were measured in the NCIR, the row and the CIR for treatment A, by taking soil samples with a needle board (1985) or vertical cores (1987).

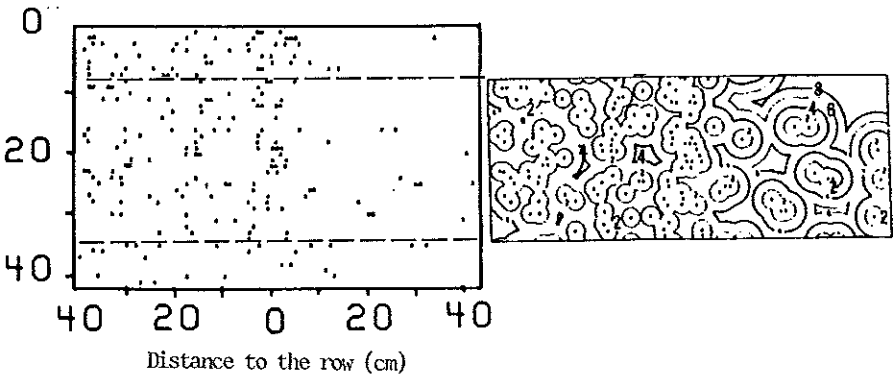

Fig. 1. Map of root contacts on a horizontal plane, and isocontours of the distance (cm) to the nearest root contact constructed on the same map. Treatment A, 60 cm depth, 1985

RESULTS

<u>1 - The vertical distribution of root contact density</u> on vertical planes is presented in Fig. 2, for maize in 1983. In C a high density was observed in the first 10 cm layer, where the soil was fragmented by the harrow;

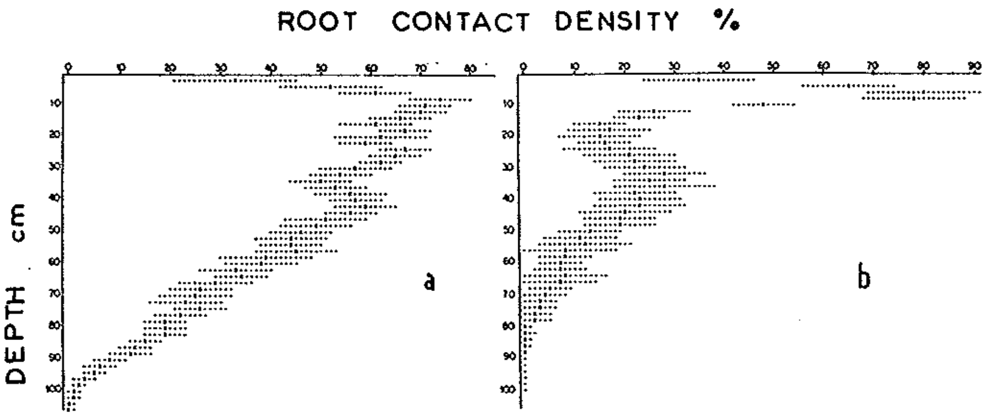

Fig. 2. Mean and confidence intervals of the proportion of 2x2 cm squares where at least one root contact was observed. Maize, silking, 1983.
a : Treatment 0 ; b : Treatment C

the compacted layer (10-26 cm) was sparsely colonized, all roots being located in shrinkage cracks which appeared in June. In the non-tilled layer, root density was lower in C compared with O, although the structure of these layers was not affected by the compaction. The maximum root depth was the same in O, B and C; roots were observed in all treatments at 120 cm.

2 - Horizontal distribution of Lv in the ploughed layer. The distance from the maize row had no effect on root contact density (Tardieu & Manichon 1986b). The frequence of 2 x 2 cm squares where one root contact at least was observed (Table 1) was considerably higher in the fragmentary zones of treatment B than in the compact ones. In O, the comparison between the clods and the fine earth yielded the same results. A chi-square test allowed to compare the distribution of frequences in each structural zone with a random distribution : a significant root clumping was observed in the fragmentary zones which had the lowest density and strength. Conversely, the spatial arrangement of broad bean roots was less affected by the soil structure : frequences were less different between each structural category, and χ^2 values were lower than for maize. Measurements carried out during the season showed that the soil water content in the clods was similar in both trials over the growing period of roots ; therefore, differences in root penetration were probably of genetic origin.

	Compact soil massive	Cracked soil massive	Fine earth and clods <3cm	Clods >3cm clods >5cm and voids	chi square
Maize					
O	-	48	71	72	162
B	7	66	-	81	632
Broad bean					
O	-	66	30	28	34
B	30	52	-	43	44

Table 1. Soil structure and colonization of the ploughed layer : proportion of 2x2 cm squares where at least one root contact was observed ; value of the chi-square in the comparison with a random distribution. Maize, 1983 : Treatments O and B ; Broad bean, 1985 : Treatments O and B

3 - Effect of the structure of the ploughed layer on spatial arrangement of roots in non-tilled layers (maize). Root contact maps obtained in treatment A (Fig. 1) were partitioned into three strips : two 25 cm-broad "inter-rows" (compacted, "CIR" and non-compacted "NCIR") and a 35 cm-broad "row". In nontilled layers, the wheel track had a high effect on root contact density (Table 2) ; conversely, no differences were found between the row and the NCIR. Measurements of Lv carried out on these three compartments in 1985 and 1987 gave results similar to those obtained by mapping (Tardieu 1988b). Therefore, obstacles to root penetration which reach the base of the ploughed layer can reduce maize root density in the underlying zones of non-tilled layers. This reduction cannot be ascribed to the soil structure in these layers, since this was not affected by compactions. It is probably due to the growth pattern of the maize root system : the obstacles caused a "shadow effect" for roots in non-tilled layers. A similar effect was observed when artificial obstacles were located at the base of the ploughed layer (Tardieu 1988a). The "shadow effect" caused a significantly clumped pattern of the root spatial arrangement, which was detected with the autocorrelation and variance/mean methods (Tardieu 1988a). A clumped pattern of root arrangement was also

observed in the nontilled layers of treatment C : the zones located beneath shrinkage cracks were significantly more colonized than the remaining parts of non-tilled layers (Tardieu & Manichon 1986b).

	1984 NCIR	1984 row	1984 CIR	1985 NCIR	1985 row	1985 CIR
20cm	23.1	20.4	4.1	36.6	30.9	2.5
40cm	13.4	12.1	3.0	14.2	14.6	2.0
60cm	9.8	9.3	3.0	10.8	11.7	1.2
80cm	5.3	4.0	1.4	4.3	3.8	0.4

Table 2. Root contact density (number.$m^{-2}.10^{-2}$) at each depth, below the non-compacted inter-row (NCIR), the compacted inter-row (CIR) and the row. Maize, 1984 and 1985

4 - Distance between roots. Results for treatments O and C, maize 1983, are presented in Fig. 3. While in treatment O, all points of the soil were at a distance smaller than 4 cm to the nearest root, down to the 60 cm depth, and appreciable proportion of points in C were at larger distances from roots. Difference between treatments was maximum in the 17-cm-deep plane, because root contacts in the ploughed layer of C were clumped in shrinkage cracks. If the distance between roots had been calculated assuming a regular pattern of root spatial arrangement, all points in the soil of treatment C would have been considered as being at a distance less than 3 cm from the nearest root, down to 80 cm (Tardieu & Manichon 1987b). A similar result was observed for treatment A (Tardieu 1988b) : an appreciable proportion of points below the CIR were at a distance greater than 8 cm from the nearest root (Fig. 1). These distances were considerably greater than half the mean distance between neighbouring roots (HMDR), calculated at the same depths form the Lv : the HMDR values for A in 1985 and 1987 were less than 2 cm down to the 80 cm depth.

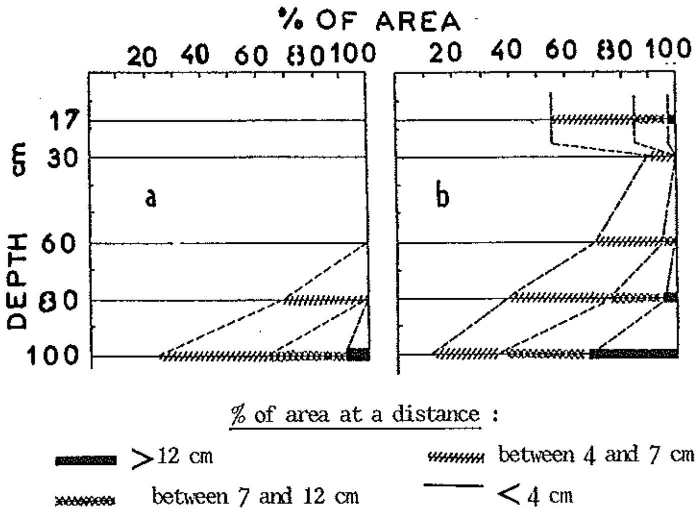

Fig. 3. Cumulative frequency distribution of the distances between each point of the 5 superposed horizontal planes and the nearest root contact

DISCUSSION AND CONCLUSION

The spatial arrangement of roots, vertical and horizontal, was strongly affected by the structure of the ploughed layer. In this layer, obstacles to root penetration caused a root clumping, which was more marked for maize than for broad bean. In non-tilled layers, decimetre-sized non-colonized zones were observed below the obstacles. The effects of wheel compactions were therefore more drastic than those which could have been predicted from models of root penetration (Barley & Greacen 1969). Severely compacted wheel tracks caused a reduction in root density not only at depths where they compacted the soil, but also in the non-tilled layers where the soil structure had not been distrubed.

As a consequence, the distance that water and mineral elements had to travel to the nearest root was much greater in the plots which had recieved a compaction than in those without compaction. The main reason for this was not a reduction in the root length per unit area, but the clumped arrangement of roots. These distances were appreciably greater than half the mean distance between neighbouring roots, although this is classically considered as the maximum distance from a point in the soil to the nearest root (Gardner 1960). These results, and the monitoring of water uptake by maize which followed the analysis of root systems (Tardieu 1987), suggest that, in compacted fields, the study of the resistance to water flow from soil to plants cannot be undertaken without taking the spatial arrangement of roots into account.

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CROP ROOT CAPABILITIES

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ABSTRACT

Four decades of root observations and measurements using many agricultural crops show two basic patterns of development. Each is rapid growing and has deep rooting characteristics. However, activity of roots is dynamic only during the vegetative stage; many rootlets and fine roots die each day while many new ones are initiated, elongate, and "search out" nutrients and moisture from "new" volumes of soil. During the fruiting stage, both top growth and root development cease; however, they are reinitiated in some long-lived taprooted species after fruit maturation. Unfortunately, crop roots very often fail to reach their full potential in fields farmed today, and yields are adversely affected. Much of this loss is directly associated with current tillage and trafficking practices.

INTRODUCTION

The effect of tillage and trafficking on soil below the visible field surface is frequently misunderstood. Equally misunderstood is the effect of tillage and trafficking on crop roots. Better information is required if crops are to prosper and if growers are to be rewarded for their efforts. More field and laboratory investigations on crop requirements and the effect of current practices on the root environment are needed.

METHODS

For the past 40 years, the author has dug trenches within fields of various soils planted to a range of crops in order to ascertain what was occurring within the soil and to crop roots. He then grew single plants, first in glass and later in clear Plexiglas fronted containers, in loose, fertile, moist soil to investigate the development of root systems throughout the entire life of each crop. He observed root development using similar plants when they lacked aeration, moisture, nutrients, or were maintained at warmer or cooler soil temperatures in order to obtain information on the effect of these conditions on growth and production.

Root counts and length measurements were made 7 days a week along the transparent windows to determine numbers, initiation rate, growth rate, and duration of activity of roots in some 80 species of plants that included trees, vegetables, fiber crops, grains, spices, and tropical plants. After root development was characterized under "ideal" soil conditions, root and top growth were studied in soil situations simulating various field conditions thought to produce some form of stress in the plant. Root tissues from plants developing both in field and controlled laboratory environments were examined microscopically to compare the results.

RESULTS

Long-Lived Taproot Systems

Seeds of many plants germinate and produce seedlings with an expanding radical which develops into a taprooted system. The root system of long-lived taprooted plants continues to elongate downward, developing lateral (secondary) branching in two planes each at right angles to the other and at a right angle from the primary, or taproot. The taproot, and only the taproot, is strongly geotropically oriented, but should it be diverted or die, a nearby secondary which is able to bypass the obstacle will develop and assume all functions of the original taproot.

During the first 24 hours of elongation, all roots are characteristically smooth and contain only cells undergoing cell division and cell enlargement. During the second 24 hours, the tip section containing cells undergoing division and elongation is forced forward; and tissue differentiation becomes more pronounced in the section more than 20 hours old and root hairs become obvious on root surfaces.

In root tissue 2 to 5 days old, lateral roots initiating from the stele begin to emerge through the cortical tissue in two planes at right angles to each other. A few days later, tertiary branching will develop similarly from the laterally oriented secondary branching. Branching in one plane may extend upward as well as downward, while roots initiating in the other plane tend to extend parallel to the soil surface. When a section of root is about a week old, cortical cells in the longer living primary and secondary roots turn brown and deteriorate. This deteriorating cortical tissue appears unable to transmit moisture and nutrients from contacted unsaturated soil, thus restricting much of the moisture and nutrient absorption to younger root tissues. Nevertheless, the stele is still alive and continues to transport substances and to develop additional branch roots.

Root development is extremely dynamic from about 3 weeks until the initiation of fruiting. During this period of rapid growth, tips of dominant roots can be thrust ahead 75 mm during a 24-hour period. Each day many thousands of new roots and fine, unbranched rootlets are initiated; most elongate for a few days and then deteriorate. These are replaced by others permeating nearby soil. Throughout the life of a single plant, an area as small as a postage stamp may be penetrated by roots and rootlets as many as 20 times. After fruiting is initiated, both root and top growth cease, but will be reinitiated in perennials after fruit maturation.

Short-Lived Taproot Systems

Many other seed types produce plants which have a short-lived taproot that is gradually transformed into what the author refers to as a nodal rooting system. In this group, a short-lived taproot is generated from the seed, but as the plant stalk ages, other roots initiate from primordia located near nodes at the base of the developing stalk. Members of the grass family have a nodal root system, but many other plant types also develop a similar system. As the initial taprooting system is discarded, the "permanent" system develops from nodes on the buried portion of each stalk or from near leaf and branch scars on buried shoots. The temporary taproot system in these plants appears to serve only to initiate and mature the shoot enough for root primordia to develop on the new stalk. As the nodal root system develops, the taproot system dies. This process may be initiated a few days after emergence and terminate in a couple of weeks. Later each sucker, or stalk, developing from the "mother" stalk will generate its own nodal root system. Soon its total source of nutrients and moisture will be supplied by its nodal root system, and the new shoot will become independent of the "mother" stalk.

Members of these plant types are adapted to survive by vegetative reproduction. After the crops are grazed, mowed, or harvested, new shoots rise from buried buds, or "eyes", on the stools, stems, corms, tubers, bulbs, and so forth. Some apparently have adequate storage to initiate a new shoot, but most initiate a temporary root system that serves until the new shoot develops its nodal root system. Some types sprig easily, develop much more rapidly, or are so genetically variable that characteristically they are vegetatively propagated. Sugarcane, for example, initiates temporary nodal roots from primordia on seed pieces, or setts, as the shoot develops. A few weeks later, the seedpiece root system deteriorates as new stalks develop their own nodal roots system.

In the characteristic nodal root system, the root primordia associated with the bottom node sends a partial ring of thin nodal roots downward, not vertically, but forming a conical surface roughly at an angle of 50 degrees from a level surface. A few days later, a second flush of thin roots develops from the second node and tends to follow the same directional pattern. Subsequently, other nodes develop more roots to pass through the same conical soil zone. A more complete ring of nodal roots is formed at about the fifth node. These roots are full sized and are capable of elongating at a rate of about 75 mm/day.

Nodal roots develop secondary laterals in two planes much like the taproot. And each nodal root develops additional branching in a manner similar to long-lived taprooted plants. Dominant roots can exceed lengths of several meters and reach a depth of 2 meters in less than a month. However, nodal rooted plants seem to develop a longer, or a denser coverage of root hairs than found on the long-lived taprooted crops that have been observed.

DISCUSSION

Roots from both plant types appear to require oxygen and photosynthates to release energy needed for cell development, moisture for cell elongation (and shoot usage), proper soil temperature for timely physiochemical reactions to occur, and there must not be anything present to inhibit root or top development. Roots appear capable of developing normally in warm, moist, well-aerated and even very acid or infertile soils as long as the plant can be supplied adequately with required nutrients from aerial application, or by other roots, to produce the metabolites needed for new root growth. Sunlight energy captured by leaf surfaces is converted to energy needed by the plant. During the first few weeks, growth is normally slow, but after the third week, the leaf area becomes sufficient to intercept enough light to initiate a period of rapid top and root development.

As the leaf area is increased and intercepts more photons of light, more sunlight energy is converted to the chemical energy needed for rapid growth and storage. Fewer hours of sunlight falling on the aerial portion of plants results in less total root elongation and the initiation of fewer new roots the next day. Colder, or warmer, soil temperatures from the optimum for a particular plant will also reduce root development or prevent it. During ideal weather conditions, root systems of all plants tested by the author at the National Soil Dynamics Laboratory were able to extend to depths of more than 180 cm in soil that was warm, moist, fertile, and well-aerated. No plant tested, whether of the long-lived taprooted type or a nodal root type, proved to be shallow-rooted.

Rapid root activities, however, occur only when the plant is provided with both a suitable aerial and root environment. Unfortunately, farmed fields are often trafficked after primary tillage which collapses air spaces in the tilled horizon. The harrowing and cultivation operations frequently loosen only the surface 20 mm. The plowed horizon below this depth is recompacted by traffic that restricts aeration. Pore space is marginal from the loosened horizon to the depth of the deepest previous tillage. The harrowsole and plow pan are usually insufficiently permeable to air, water and roots for good top growth. A rhizosphere with less room for oxygen seems responsible for slowing the creation of new cells in active root tissue since oxygen has been found necessary for cell division. With a reduction in the number of new cells formed, there is a notable decrease in the rate that a root tip is thrust forward during cell enlargement. When root elongation is slowed, less new moist soil is contacted, thereby reducing the rate of moisture absorption and increasing the probability that stomates on plant leaves will be closed. This can reduce or even prevent photosynthetic activity.

Rapid root development occurs after a seedling is about 3 weeks old and extends until flowering. It is imperative that the time be completely utilized, since with many plants this approximate 6-week period determines the size of the plant and its capacity to manufacture metabolites. When the plowed horizon is recompacted and root activities are slowed, less of the available sunlight energy can be converted into yield. In soil on farms that depend on motorized farming operations, root elongation rates rarely exceed 10 mm/day. New branch root development is also lessened severely. Often new root development is confined to fracture planes within the soil where air and moisture are available and will not penetrate into the massive soil between fractures.

Once moist soil is tilled, its structural strength cannot resist applied forces without significant collapse, resulting in compaction. After becoming compacted, porosity must be improved for roots to develop to their full capacity. Long-lived taprooted plants seem to grow better than nodal rooted plants when a surface horizon is compacted and the undisturbed soil beneath has fair porosity. Once the tap root works its way through the compaction, it can function normally in the better aerated soil below. However, nodal rooted plants must continually force new roots through the compact horizon to obtain moisture. During drought conditions, additional nodal roots cannot pass through the soil zone from which the earlier roots have already removed the moisture. Taprooted plants appear capable of developing the essential additional rooting beyond the desiccated horizon.

Traffic control appears to be needed to reduce compaction in the tilled horizon. Uncompacted production strips appear to increase moisture capture and improve root development in all tilled fields where a mechanized agricultural system is utilized. Not only must traffic by heavily laden tractors, equipment, and trucks be controlled, but traffic by all other wheels, including guide and support wheels on light implements, and even disk harrow blades. Forces from such implements can compact tilled soil sufficiently to reduce root activity to 25% of its capability and reduce water insoak to where up to 90% of an intense rain can wash from soil surfaces, taking with it applied chemicals, fertilizers, and irreplaceable topsoil. Forces as low as 25 kPa have been observed to seriously compact well-tilled, moist soil.

SUMMATION

After looking at the effects of machinery on soil and roots, it must be concluded that today we are almost totally ignoring the needs of the root system. We intentionally cultivate in order to encourage and enhance propagation of selected crops in an environment better adapted to "native" plants. Fortunately, crops often survive in spite of misdirected efforts. We are recompacting the very soil horizon we have attempted to improve. Root development and growth are adversely affected; production is reduced and operational costs are increased. Crops must be given an opportunity for roots to develop to their full potential if farmers are to feed an expanding population. And farmers must learn to control traffic for agriculture to be profitable and sustaining.

WATER RETENTION AND SOIL PHYSICAL PROPERTIES FOLLOWING THE DEEP LOOSENING OF A SILTY CLAY LOAM

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ABSTRACT

A long-term field experiment was set up to investigate the effect of soil loosening on water retention and soil physical properties in a structurally unstable silty soil in Devon, U.K. Following the installation of an underdrainage system, half the experimental site was loosened to a depth of 0.4m. The whole site was then cultivated prior to sowing winter wheat. Intensive monitoring of soil water energetics and strength characteristics was carried out during the autumn, winter and spring following deep loosening. The loosened profiles show, on average, 5% greater water retention in the 0.20-0.40m zone, caused by a modification of the pore size distribution associated with the deep cultivation. Soil shear strength is reduced as a direct consequence. This has important implications for soil trafficability during periods when water contents approach winter mean levels.

INTRODUCTION

Good management of agricultural soils depends upon cultivating at water contents low enough such that structural damage does not occur. In the western and northern regions of the United Kingdom such cultivation opportunities are often limited by both climate and soil type. Efficient drainage is therefore a pre-requisite for arable cropping. This paper presents some results obtained during a study of the effect of soil loosening on soil water dynamics and drainage efficiency. The soil in question, a silty clay loam developed over Devonian slate, is structurally unstable and stony in places; therefore mole drainage is not a suitable secondary treatment to encourage rapid water disposal. In recent years many shallow subsoilers or soil looseners have become available to farmers, with often ambitious claims as to potential benefits from regular soil loosening. These include relief from compaction, more effective drainage and improved crop yield. Experiments conducted in the United States (Musick and Duseck, 1975) and the United Kingdom (Dawkins _et al_, 1984) have confirmed the benefit to the crop from soil loosening. This study has concentrated on the modification of the soil physical environment and water transmission routes following loosening of a structurally unstable soil. Preliminary analyses of water retention and disposal processes have been reported elsewhere (Parkinson _et al_, 1987).

The observations reported here are confined to one twelve month period, concentrating on the influence of small changes in soil water content on the trafficability of the soil in the critical autumn and spring periods.

EXPERIMENTAL SITE AND METHODS

A system of six 80mm drains were laid 20m apart and at a depth of 0.75m on a gently sloping (7%) site at Seale-Hayne College Farm, Devon, U.K. The silty clay loam topsoil overlies a gleyed silty clay subsoil, which passes down to weathered slate at a variable depth of between 0.4 and >1.0m. This soil most closely resembles the Sportsmans Association (Findlay et al, 1984).

Following the installation of the drains in September 1985, the site was monitored for twelve months to establish patterns of soil variability. In September 1986, following the harvest of a winter wheat crop, half the site was loosened to a depth of 0.40m. The whole site was then ploughed and cultivated prior to drilling the next winter wheat crop.

During the autumn, winter and spring 1986/87, soil physical conditions and soil water properties were monitored intensively. Soil water content was determined at weekly intervals using a neutron probe. Matric potential was measured manually using mercury manometer tensiometers, values being adjusted for gravitational potential differences according to depth of tensiometer burial. Shear strength was assessed on three occasions using a hand held shear vane.

RESULTS

In simple terms, soil loosening increases porosity. However, it is important to identify changes in the pore size distribution and in particular the different proportion of those pores which store water and those which contribute to drainage processes. When measured at weekly intervals patterns of change of soil water content can be used to illustrate differences in water storage. Volumetric water contents for the loosened and unloosened soils down to 0.80m are displayed in Fig. 1. For each treatment the soil water content is the mean of readings taken at three access tube locations. Profile rewetting continued during September, with winter mean water contents, as defined by Reid and Parkinson (1987), being reached by the fourth week in October. The loosening has a very pronounced effect on water storage, increasing mean winter water contents by over 6%. Drying of the profile began in the second week of April, shortly after which the final shear vane readings were taken.

Associated with the increase in porosity on loosening is an expected decrease in bulk density. As the whole site was ploughed following loosening, the surface horizons shows no statistically significant differences (see Fig. 2) but below 0.2m the effects of loosening are obvious. These effects persist down to 0.40m at which point the curves become statistically indistinguishable. In addition to quantifying the total pore space, it is necessary to describe in detail the changes in the pore size distribution caused by the loosening operation. This can be carried out in the laboratory directly, by equilibrating cores on tension tables, or in situ describing relationships between the water content and matric potential using tensimeters. In this experiment both methods were used, but only in situ tensiometer readings are reported.

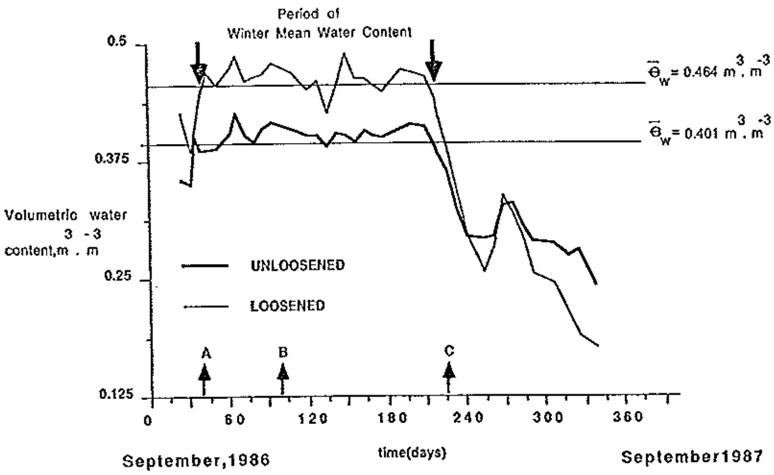

Figure 1 Soil water content for 0.80m deep profile, 1986-Sept 1987. A, B and C indicate dates at which matric potential and shear vane readings were taken.

In Fig. 3, soil matric potential (i.e. total potential - gravitational potential) is plotted against soil depth for three occasions, October 10th, December 5th and April 10th, corresponding to a wetting profile, a winter mean water content profile and a profile during the early stages of drying. Each point is the mean of three replicated observations.

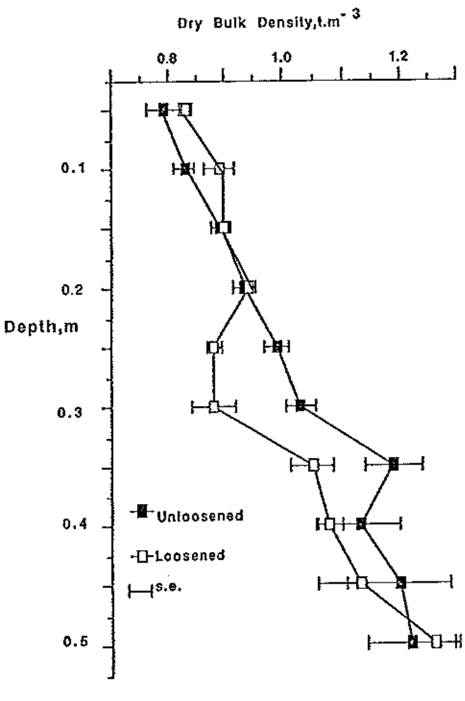

Figure 2 Variation of dry bulk density with depth.

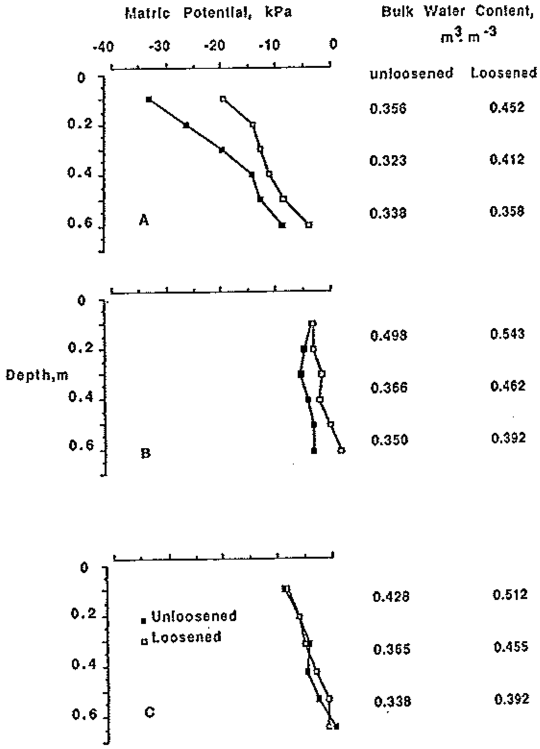

Figure 3 Matric potential profiles recorded on three occasions during 1986-87 drainage season. A. Wetting profile. B. Profile at winter mean water content. C. Drying profile.

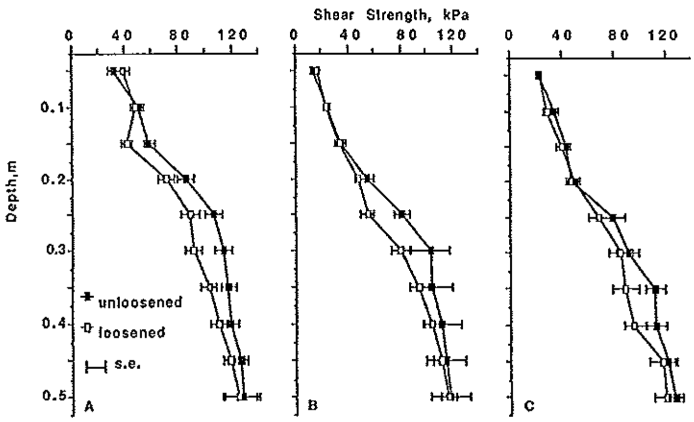

Figure 4 Effect of loosening on soil shear strength on three occasions during 1986-87 drainage season.

The wetting profile (Fig. 3A) shows very clearly that loosening has reduced matric potentials and hence increased soil water contents. The latter are given for bulked depth zones 0-0.20m, 0.20-0.40m and 0.40-0.60m. This effect occurs not only in the loosened zone, but also nearer the soil surface, despite the fact that bulk densities are similar.

The winter profile of matric potential varies little with depth but water contents are much higher nearer the surface, reflecting the increased volume of water storage pores. In the early stages of spring drying (Fig. 3C) tension profiles are similar but the loosened soil still remains wetter. An important consequence of this soil water behaviour is that soil shear strength is modified, in particular below the plough layer. Superimposed upon a general trend of increasing shear strength with depth (Fig. 4) can be seen the the divergence of the curves within the loosened zone. The higher water contents and the mechanical disruption caused by the loosening operation has produced significantly lower shear strengths, particularly at 0.25 and 0.30m. The effect varies according to time of sampling. Even observations taken over a time span of as little as six months illustrate a progressive increase in the depth of maximum difference (Fig: 4A, B and C). A correlation of all the shear vane observations indicates that bulk density correlates most strongly with shear strength, followed by water content and matric potential (Table I).

	Dry Bulk Density $t.m^{-3}$	Water Content $m^3.m^{-3}$	Matric Potential kPa
Vane Shear Strength kPa	0.89***	-0.666***	-0.218*

*** P < 0.001
* P < 0.05

Table I Correlations between vane shear strength and either dry bulk density, water content and matric potential.

DISCUSSION AND CONCLUSION

That soil loosening increases soil water storage pore space as well as drainable pore space is well known (Musick and Duseck, 1975; Unger et al, 1982). However, the consequences in terms of soil shear strength reported here are of vital importance for good soil management. The higher water contents and lower matric potential consistently observed on the loosened plots throughout the period from October to April result in lower soil strength and bearing capacity, particularly in the loosened layer. Effects nearer the surface, where ploughing and secondary cultivation have subsequently been carried out, are less pronounced, particularly towards the end of winter (Fig. 4C). The correlation between the physical parameters investigated is closest in the case of bulk density and shear strength, although water content and matric potential are also significantly related. Similar relationships were identified by Douglas (1986) for a range of cultivation treatments.

In conclusion, it can be stated that on unstable soils, loosening must be carried out with caution. Attempts to increase drainage efficiency can lead to higher water contents and reduced machinery access. Further work is being carried out to investigate the temporal persistence of the loosening treatment on soil physical conditions.

ACKNOWLEDGEMENTS

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TILLAGE EFFECTS ON SOIL CONDITIONS OF THE UPPER ROOT ZONE

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ABSTRACT

Because tillage loosens the soil, no-tillage seemingly should cause soil conditions unfavorable for crop production. However, crop yields have been favorable with no-tillage in the semiarid region of Texas. In this study, we measured water retention, organic matter content, mean weight diameter, bulk density, and penetrometer resistance of Pullman clay loam (Torrertic Paleustoll) that was managed by conventional and no-tillage methods. Some factors were significantly affected, but there was no consistent advantage nor disadvantage for either method. Crop yields averaged 5,320 kg/ha with no-tillage and 5,100 kg/ha with conventional tillage in 1987.

INTRODUCTION

Tillage loosens the soil and, thereby, improves conditions for water infiltration, crop establishment, and plant growth. This implies that soil conditions with no-tillage might be inferior to those of tilled soil. Tillage disrupts crusts, alleviates compaction, and increases porosity, which increases infiltration and reduces runoff and soil losses.

Lower bulk density, penetrometer resistance, compaction, and/or higher water infiltration on conventional than on conservation (reduced- or no-) tillage areas were reported by Dickey et al. (1983), Hamblin et al. (1982), Lindstrom and Onstad (1984), and Whitely and Dexter (1982). Others (Lal, 1986; Mielke et al., 1984; Packer et al., 1984; Unger, 1984) reported that soil conditions were similar or better with conservation than with conventional tillage. Surface residues were important for maintaining or achieving favorable conditions with conservation tillage.

No-tillage studies involving dryland winter wheat (<u>Triticum aestivum</u> L.) and grain sorghum [<u>Sorghum bicolor</u> (L.) Moench] were initiated at Bushland, Texas (U.S.A.) in 1979. Both crops yielded slightly more grain with no-tillage than with conventional (stubble mulch) tillage (O. R. Jones, Bushland, Texas, personal communication, 1987). Observations at Bushland indicated that soil physical conditions were better on no-tillage than on tillage areas, especially near the end of fallow that followed wheat in the rotation (two crops in 3 years). The objectives of this study were to compare the upper root zone soil physical conditions of no-tillage and conventional tillage fields.

METHODS AND MATERIALS

The study was conducted at the USDA Conservation and Production Research Laboratory at Bushland, Texas (U.S.A.), on a Pullman clay loam (Torrertic Paleustoll). Samples were obtained in spring 1987 from fields used for a winter wheat and grain sorghum rotation (two crops in 3 years). The fields were in fallow after wheat (harvested in June 1986) at the time of sampling.

The soil has less than 1% slope and contains about 17% sand, 53% silt, and 30% clay in the surface horizon (0- to 15-cm depth) (Unger and Pringle, 1981). The clays are mainly illonite and montmorillonite (Taylor et al., 1963), which results in a major shrink-swell potential. The soil may freeze about 15 cm deep. Most precipitation occurs from May to September, but snow is possible.

Three fields were sampled for the study. Field 1 (NT-6) was in no-tillage for 6 years (since 1981), Field 2 (CT) was an adjacent conventional (long-term stubble mulch) tillage watershed, and Field 3 (NT-8) was in no-tillage for 8 years (since 1979) and was about 0.4 km from Fields 1 and 2. Samples were obtained at four sites (replicates) and near the midpoint of 0- to 10-cm (tillage zone of CT) and 10- to 20-cm depth increments in each field. The CT field was not plowed since the fall of 1986.

A 1-liter bulk soil sample was obtained at each position. While still moist, the soil was passed through a 12.7-mm sieve, then air-dried before determining aggregate size distribution by wet sieving (Kemper and Chepil, 1965). Subsamples were ground before determining organic matter content by the modified Walkley-Black procedure (Jackson, 1958). All determinations were made on duplicate samples.

Besides the bulk samples, 10 cores (54 mm diam. and 30 mm high) were obtained at each site and depth. The cores were trimmed, saturated with water, weighed, and subsequently weighed again after equilibrating to 10, 25, and 50 cm water tension. After the final equilibration and weighing, 10 penetrometer (4.76-mm diam. flat point, Model 719-5MRP, John Chatillon & Sons, Kew Garden, NY 11415) measurements were made on each core. The cores were dried at 105°C and weighed before calculating soil water contents and bulk density.

Data were analyzed by the analysis of variance technique, and Duncan Multiple Ranges and protected least significant differences (Prot. LSD) were determined to show which differences were significant at the 5% ($P = 0.05$) level.

RESULTS AND DISCUSSION

Soil water content (WC) at saturation at the 0- to 10-cm depth was highest on the NT-6 field and lowest on the CT field (Table 1). At the 10- to 20-cm depth, the differences were not significant. At 10 and 25 cm tension, WC differences due to fields and sampling depths were not statistically significant (data not shown). At 50 cm tension, WC was highest on the NT-8 field and increased significantly with depth on the CT and NT-6 fields.

High WC at saturation indicates high total porosity. As the soil drains due to increasing tension, large pores drain more readily than small pores. The data indicate that the NT-6 soil at the 0- to 10-cm depth had more large and fewer small pores than the CT and NT-8 soils because these latter soils had lower WC at saturation and higher WC at 50 cm tension. The change in WC from saturation to 50 cm tension was 0.062, 0.134, and 0.059 percentage units for the CT, NT-6, and NT-8 soils, respectively. At the 10- to 20-cm depth, the WC changes were 0.053, 0.061, and 0.045 percentage units for the respective soils.

The higher WC at all tensions (10, 25, and 50 cm) and the smaller change in WC from saturation to 50 cm tension for the NT-8 soil at the 0- to 10-cm depth suggests that this soil has relatively fine pores, which could lead to aeration problems. Poor crop yields on poorly-drained soils were obtained with no-tillage in humid regions (Triplett et al., 1970). However, no aeration and drainage problems associated with no-tillage have been encountered on this soil, even when irrigated. The need for water conservation greatly exceeds the need for drainage in most years in the semiarid region of Texas where this study was conducted.

Organic matter (OM) contents of CT and NT-8 soils at both depths were similar and were significantly higher than that of the NT-6 soil (Table 1). The low OM content of the NT-6 soil and the surprising similarity in OM content of the NT-8 and CT soils may have resulted from removing (nonsampling) the surface 3 or 4 cm of soil. Sampling nearer the surface possibly would have resulted in a higher OM content of the NT-8 soil because of the residues maintained on the surface. On the CT field, tillage more uniformly distributed the OM in the tillage zone (0- to 10-cm depth).

The mean weight diameter (MWD) of water stable aggregates was higher at both depths on the NT-8 field than on the CT and NT-6 fields (Table 1). On the CT field, MWD increased with depth, which suggests low stability of the soil when wetted (for example, by rainfall) and could lead to soil surface sealing and greater runoff than from more stable and/or protected surfaces. Benyamini and Unger (1984) obtained greater surface sealing and lower infiltration of simulated rainfall on bare-surfaced than on residue-protected Pullman soil. The MWD on the NT-6 field probably is lower than on the NT-8 field because the NT-6 field has a shorter history of no-tillage management. The lower OM content on the NT-6 field also may be a factor.

Soil bulk density (BD) at the 0- to 10-cm depth was highest on the CT area, followed by that on the NT-8 and NT-6 fields (Table 1). All BDs were identical at the 10- to 20-cm depth. The high BD on the CT field was not expected because soil at the 0- to 10-cm depth was loosened by tillage. However, the tillage was performed about 6 months before sampling, and rainfall had consolidated the loosened soil. Undoubtedly, the unstable (low MWD) soil on the CT field resulted in relatively rapid consolidation. Contributing to the relatively low BD on the NT-6 and NT-8 fields was soil disturbance during wheat seeding.

Soil penetrometer resistance (PR) was greatest on the NT-8 field and least on the NT-6 field at the 0- to 10-cm depth (Table 1). At the 10- to 20-cm depth, PR differences were not significant. The PR was high on cores from the NT-8 field, even though those cores had an intermediate BD and the highest WC when the PR measurements were made. These results (high PR, low BD, and high WC) are contrary to PR trends frequently encountered and suggest that no-tillage soils cannot be satisfactorily characterized by measuring a given soil factor and/or condition. The high PR in spite of the high WC and relatively low BD may be due to the high MWD, which indicates a relatively high percentage of water stable aggregates. High aggregate stability also indicates a stable pore system. The latter was suggested by the relatively small change in soil WC with tension increases from saturation to 50 cm of water.

GENERAL DISCUSSION

Although significant differences in soil conditions existed among the conventional tillage (CT) and no-tillage (NT-6 and NT-8) fields, most differences were relatively small, and there were no definite advantages for either tillage method. The data suggested that the NT-8 field (no-tillage since 1979) soil had a fine pore system which possibly resulted in the higher penetrometer resistance. However, the mean weight diameter was greater and the bulk density was lower for the NT-8 than for the CT field. Organic matter contents were similar on the two fields.

From these data, it is concluded that no-tillage does not adversely affect Pullman soil physical conditions under present management practices. In addition, crop yields are favorable on the no-tillage areas. Dryland grain sorghum grain yields averaged 5,100, 5,280, and 5,360 kg/ha on the CT, NT-6, and NT-8 fields, respectively, in 1987, which was a very favorable year. An advantage of the no-tillage system has been improved water conservation, undoubtedly because of the crop residues retained on the soil surface.

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Table I. Soil conditions of conventional tillage (CT) and no-tillage (NT-6 and NT-8)[1] fields, Bushland, TX, 1987.

Measurement	Depth	CT	NT-6	NT-8	Mean
Water content -- m^3/m^3:					
At saturation	0-10	0.462	0.525	0.493	0.493a[2]
	10-20	0.477	0.484	0.470	0.477b
	Mean	0.470b[2]	0.505a	0.482b	
	Field x Depth --- Prot. LSD[3] = 0.031				
At 50 cm tension	0-10	0.400	0.391	0.434	0.408a
	10-20	0.424	0.423	0.425	0.424a
	Mean	0.412b	0.407b	0.430a	
	Field x Depth --- Prot. LSD = 0.022				
Organic matter content -- g/kg:					
	0-10	18.1	14.2	17.7	16.7a
	10-20	14.3	12.9	14.4	13.9b
	Mean	16.2a	13.6b	16.0a	
	Field x Depth --- NS				
Mean weight diameter (MWD) -- mm:					
	0-10	1.04	1.41	2.81	1.75a
	10-20	1.97	1.52	2.65	2.05a
	Mean	1.51b	1.46b	2.73a	
	Field x Depth --- Prot. LSD = 0.60				
Bulk density -- Mg/m^3:					
	0-10	1.50	1.30	1.43	1.41b
	10-20	1.46	1.46	1.46	1.46a
	Mean	1.48a	1.38c	1.45b	
	Field x Depth --- Prot. LSD = 0.03				
Penetrometer resistance -- MPa:					
	0-10	0.50	0.29	0.57	0.45b
	10-20	0.70	0.75	0.66	0.70a
	Mean	0.60ab	0.52b	0.62a	
	Field x Depth --- Prot. LSD = 0.13				

1/ NT-6 and NT-8 (no-tillage) fields were last tilled 6 (in 1981) and 8 (in 1979) years before sampling, respectively.
2/ Mean values followed by the same letter(s) are not significantly different (Duncan Multiple Range Test, 5% level).
3/ Protected least significant difference.
4/ Not significant at 5% level.

SOIL MANAGEMENT FOR AN OPTIMAL SOIL STRUCTURE FOR GRAPEVINE ROOTS

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ABSTRACT

Profile modification techniques were evaluated at different localities for their suitability to create a homogeneous rooting medium to a depth of 90 cm. The number of vine roots per unity soil volume was primarily determined by the available soil depth and secondarily by the quality of the rooting medium. A clear tendency for better grapevine performance with increasing soil depth was established. Minimum tillage comprising of a mulch on the soil surface is recommended for vineyards. The mulching material is produced by a winter growing cover crop which is sprayed with herbicides in early spring.

INTRODUCTION

Unfavourable soil physical and chemical conditions in many soils impede grape-vine root penetration to such an extent that these soils are unacceptable for economic viticulture (Schulte-Karring, 1976; Saayman, 1982; Conradie, 1983; Van Huyssteen, 1983). These problem soils can only be rectified by expensive deep tillage to a depth of at least 90 cm so that the soil profile is altered by complete breaking up and elimination of contrasts between the soil layers, the so-called profile modification.

The favourable conditions of the surface horizons of many South African vineyard soils were destroyed in the past because of the necessity to control summer weeds. Furthermore, the effect of tillage extends as deep as 600 mm below the soil surface. This was shown for compaction by wheels (Van Huyssteen, 1983), the formation of a tillage pan at the working depth of the implement (Van Huyssteen & Weber, 1980a), the compaction caused by the building up of fine soil particles washed down by water percolating through the profile (Gabriels & Moldenhauer, 1978) and soil water conservation in the deeper layers (Van Huyssteen & Weber, 1980b; Van Huyssteen et al., 1984).

The purpose of this paper is to summarise only the most pertinent data of completed soil management trials conducted at the V.O.R.I. that effectively demonstrated the effect of soil tillage on soil physical conditions and grapevine root distribution.

MATERIALS AND METHODS

The effect of depth, method of soil preparation and organic material on grapevine performance was studied in two separate long-term experiments. In the Breede River Valley irrigation area a Chenin blanc/101-14 Mgt vineyard on a calcareous sandy clay loam soil was studied (Saayman & Van Huyssteen, 1980). Furthermore, soil preparation systems were compared for a Colombar/143B Mgt vineyard on an acid sandy clay loam soil in the Cape coastal area (Saayman, 1982). The soil preparation treatments applied are summarised in Tables 1 and 2. Two supplementary irrigations of ca. 50 mm each were applied in December and January in the Colombar vineyard. The Chenin blanc vineyard was irrigated according to evaporative demand (Class A evaporation pan) which amounted to approximately 600 mm irrigation water per year.

TABLE 1. Mean root distribution with depth and grapevine performance under different soil preparation methods on an acid sandy clay loam soil in the Cape coastal area (adapted from Saayman, 1982)

Treatment	Total number of roots	Root distribution (% of total) Soil depth (cm)					Average grapevine performance (kg/vine)	
		0-25	25-50	50-75	75-100	100-125	Shoot mass	Yield
A	271	50.2	31.0	12.2	5.9	0.7	0.704	5.52
B	356	38.5	34.0	16.3	9.5	1.7	0.844	6.59
C	527	33.2	28.8	30.2	7.2	0.6	1.027	8.13
D	563	25.4	36.1	30.9	6.6	1.1	1.002	8.24
E	595	17.5	31.3	37.0	13.4	0.8	1.055	8.17

A = Shallow plough, 22 cm deep
B = Ripper, zoned loosening to a depth of 70 cm
C = Delve plough, 70 cm deep
D = Delve plough, 70 cm deep + 25 t straw/ha
E = Delve plough, 70 cm deep + 23 t compost/ha

TABLE 2. Mean root distribution with depth and grapevine performance under different soil preparation methods on a calcareous sandy clay loam soil (adapted from Saayman & Van Huyssteen, 1980)

Treatment	Total number of roots	Root distribution (% of total) Soil depth (cm)				Average grapevine performance (kg/vine)	
		0-25	25-50	50-75	75-100	Shoot mass	Yield
A	331	26.0	36.2	28.4	9.4	1.46	10.40
B	434	21.9	35.2	35.5	7.4	1.86	10.89
C	482	19.5	27.0	23.2	30.3	1.81	11.91
D	466	16.1	29.2	27.0	27.7	1.58	11.20

A = Shallow plough, 60 cm deep
B = Ripper, zoned loosening to a depth of 80 cm
C = Delve plough, 90 cm deep + 28 t straw/ha
D = Delve plough, 90 cm deep + 28 t compost/ha

A third soil preparation trial comparing different implements and working depths was conducted under dryland conditions on a granitic clay loam soil at Stellenbosch. This soil had a root impeding bulk density of 1750 kg/m^3 in the naturally compact layer between 45 cm and 105 cm depth (Van Huyssteen, 1983). The treatments are summarised in Fig. 1.

Changes in soil properties were studied in experiments in which minimum and conventional tillage techniques were compared under both dryland and intensive irrigation conditions. Different cover crops and natural weeds were grown in the vineyards during the winter months. The following management practices are the most important ones that were evaluated: Clean tillage with a disc-harrow to work the cover crop under and to keep the vineyards weed-free during the summer months; Permanent swards where the cover crops were only mowed and left to compete with the grapevines; Full surface herhicide application to kill cover crops and weeds and to leave the dead material on the surface as a mulch. The effect of 60 cm deep cultivation, and resulting root pruning in existing vineyards were also investigated.

RESULTS AND DISCUSSION

A clear tendency for more roots and better vine performance with increasing soil volume emerged from the coastal area data (Table 1). The delve ploughed treatments had on average more than double the total number of roots compared to the shallow ploughed treatment. In the case of the shallow ploughed (33) and ripped (58) soils fewer roots were found in the 50-75 cm depth layer than in the 0-25 cm (Av. = 137) and 25-50 cm (Av. = 103) depth layers. This was due to the fact that neither of these two treatments loosened the soil deeper than 50 cm. However, all three delve ploughed treatments had much more roots (Av. = 184) in the 50 - 75 cm depth layer than the two above-mentioned treatments. It was only deeper than 75 cm that root penetration was definitely impeded in the delve ploughed soils (Table 1). These differences in root distribution correlated with the bulk densities of the specific soil layers. The bulk densities of the 50 - 75 cm soil layer were respectively 1726, 1710 and 1477 kg/cm^3 for the shallow ploughed, ripped and delve ploughed soils. No clear effect of organic material additions was evident on the shoot mass, yield or root numbers of the experimental vineyard. The constant ratio of fine:total roots (Av.=92.1 %) for all treatments indicated that no one root size was affected more than any other by manipulation of the soil physical condition (data not shown).

Comparing root distribution in the 0 - 50 cm soil layer, expressed as percentage of the total roots (Tables 1 & 2), it appears as if the grape-vines produced more roots in the upper soil layers when subsoil conditions are unfavourable. Root mass data also indicated this, and in the calcareous soil the shallow ploughed and ripped plots contained 80.1 % and 82.5 % of the total root mass in the 0-60 cm depth layer whereas the corresponding figure for the delve ploughed plots was 64.8 %. However, the actual root numbers in these layers disprove such a conclusion as the delve ploughed soils had the highest root densities of all treatments in the 0-50 cm soil depth. Therefore, the grapevines did not respond with higher root densities in one soil layer to compensate for unfavourable conditions in another.

In the coastal area the shallow and irregular depth of root distribution, roughly conforming to the loosening effect of the implement, was evident in the case of shallow ploughed and ripped plots (Saayman, 1982). Nevertheless, occasional deep penetration of roots on these two treatments still occurred into the soil layers deeper than 50 cm (Table 1).A relatively uniform root distribution was obtained down to the working depth of 75 cm of the delve plough. According to Saayman (1982) a limited colonisation of the loosened subsoil by roots took place even at the unfavourable low pH of 3.85 (1 N KCl) in the Stellenbosch soil.

No statistical significant differences with regard to grapevine performance existed amongst the soil preparation treatments reported in Table 2 (Saayman & Van Huyssteen, 1980). The soil was of such a nature that, irrespective of treatment, fairly homogeneous rooting to a depth of as much as 75 cm was possible on most of the plots compared to the only 50 cm reported in Table 1. Furthermore, the occasional deep root penetration of 9.4 % and 7.4 % into the 75 - 100 cm soil depth layer of the shallow ploughed and ripped plots repectively, together with the irrigation, contributed to the general lack in vine response. Again, addition of 28 t compost per ha before planting had no visible effect on root distribution. In agreement with the coastal area results, fine roots (< 2 mmϕ) again constituted an almost constant percentage of the total root number (Av. = 70.6 %) on all treatment plots, except for the 62,9 % of the ripped treatment.

A penetrometer study in both of the two above-mentioned experiments demonstrated that effective soil depth was directly related to grapevine performance (Saayman & Van Huyssteen, 1980; Saayman, 1982). Despite large differences in penetrometer soil strength on the granitic soil type (Fig. 1) no clear effect of soil preparation techniques on grapevine performance was measured (data not shown). The fairly good root distribution to a depth of 50 cm together with the occasional deep penetration of roots through cracks to at least 75 cm on the shallow ploughed plots (data not shown), could possibly explain the lack in vine response.

The penetrometer proved to be an effective instrument to evaluate the effect of different soil management techniques on soil loosening. Mixing and breaking up of the compact subsoil by deep single direction delving (DSD) to a depth of 80 cm was inadequate to homogenise the soil profile (Fig. 1). The unexpectedly high soil strengths in the 0 - 30 cm depth of DSD were due to large clods. The negative effect of clods on root development, due to its restricting effect on effective rooting volume, was reported by Schulte-Karring (1976) and Saayman (1982). Double delving (DD) not only reduced soil strength at all depths to values less than those measured for any other soil preparation method, but also created significantly lower soil strengths at all depths compared with DSD. In addition, the effective working depth for DD was 10 cm deeper than for DSD. The wing plough also created favourable soil strengths comparable to that of DD. Shallow ploughing was totally ineffective in creating a large enough rooting volume measured on the basis of soil strength.

Changes in root distribution were observed in a number of experiments comparing minimum and conventional tillage techniques. There were virtually no roots in the 0 - 20 cm soil depth of both continuous clean tillage and permanent sward treatments due to frequent cutting of the roots by implements and root competition by the weeds, respectively. In contrast, as much as 18.0 % of the total number of roots were found in the upper 20 cm of the no-tillage treatments, viz. straw mulch and complete chemical control. In the sward and clean tillage treatments the total number of roots were respectively reduced to 55.4 % and 58.8 % of the totals found in the above-mentioned no-tillage plots (Van Huyssteen and Weber, 1980c). A relatively compact surface soil layer with a soil specific equilibrium bulk density (1544 kg/m^3) was formed under the no-tillage practices of the above-mentioned experiment. The surface soil layer of the conventional tillage plots was very loose, but changed abruptly to a definite compact layer at 20 - 30 cm depth (density = 1704 kg/m^3). The no-tillage plots (herbicides, straw mulch and permanent sward) were obviously less compact at this depth with bulk densities being 1371, 1591 and 1542 kg/m^3 respectively. These results were repeated at three different locations (Saayman and Van Huyssteen, 1983; Van Huyssteen **et al.**, 1984). Root distribution patterns in tillage experiments could not be correlated with grapevine performance because effects such as weed competition, water shortage and nutrient supply affected vine performance through the root system although the effects might not be reflected by root distribution in the topsoil layers.

During deep (60 cm) loosening of soils in existing vineyards to overcome the negative effects of recompaction, root pruning inevitably takes place but new roots formed near the severed tips. This regrowth of the roots together with the newly created living space led to better grapevine performance (Van Zyl and Van Huyssteen, 1986).

CONCLUSIONS

1. Grapevine performance increased linearly with increasing soil depth created by deep soil tillage.
2. Effects of deep soil tillage were more pronounced in lesser irrigated vineyards.
3. Soil depth should not be the only measure of efficiency of deep soil tillage - the homogeneity of loosening and clod size also determined the efficiency of a specific profile modification technique.
4. The beneficial soil structure created by deep ploughing in existing vineyards should be stabilised and maintained by growing a winter cover crop. Shortly before bud burst of the grapevines, the cover crop is sprayed with herbicides and left as a mulch on the surface. The only mechanincal cultivation to be allowed will be to establish a seedbed for the cover crop.

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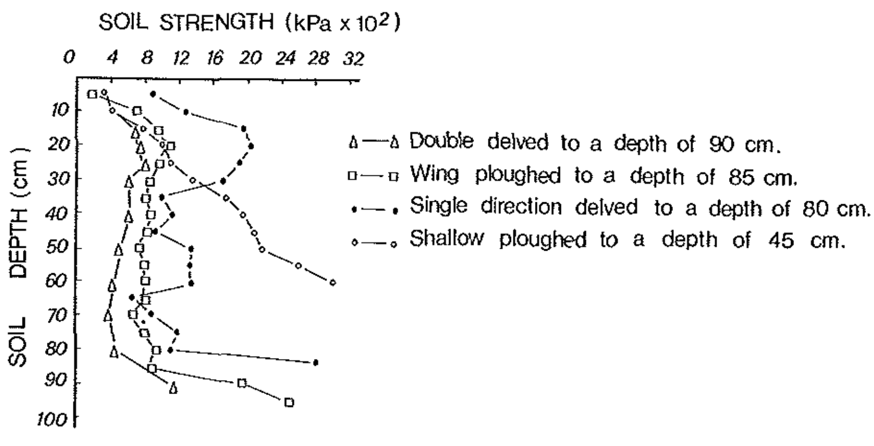

Fig. 1. Effect of different profile modification methods on penetrometer soil strength on a granitic clay loam soil (Van Huyssteen, 1983).

EFFECT OF PLANT ROOTS ON SOIL STRENGTH

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ABSTRACT

Roots of plants have been shown under some circumstances to increase soil strength. A pot experiment was conducted using rice soil from East Java, Indonesia which was puddled or not puddled and with "wet" and "dry" soil conditions and plants were grown in half the pots. Bearing capacity and shear vane resistance of soil was measured, 45 and 70 days after emergence.

The results showed that roots of rice increased both shearing resistance and bearing capacity. The relationship between bearing capacity and shearing resistance confirmed earlier results. The implication of these results on traffic in wet soils is discussed.

INTRODUCTION

Roots of plants have been shown to stabilize soils in dryland agriculture, see for example Tisdall and Oades (1980) who showed that as root length increased so water-stable aggregates increased. The practical application of their work was to suggest crop rotations in order to maintain satisfactory stability of soil structure. It is also known that roots increase the shearing resistance of soils and in the case of sloping land can be used to increase the stability of slopes to reduce erosion. Waldron (1977) and Waldron and Dakessian (1982) showed in laboratory experiments that plants such as pine, oak, lucerne and a range of grasses increase shearing resistance. In their experiments they grew plants at field water contents but measured shearing resistance at water contents near to saturation, i.e. the water content at which slopes are most unstable.

Another situation in which a knowledge of soil strength (bearing capacity and shearing resistance) is important is in puddled soil. Traffic in rice soils after rice is planted, usually human traffic, is high because of weeding and fertilizer application and whether these soils with roots are better able to support traffic is important to know on the basis that large areas of the world are used for this culture. How roots influence soil strength is important too in irrigated agriculture of row crops (maize, soybeans, sunflowers etc) because traffic on such plots is often limited immediately after irrigation. In recent experiments to measure the change in soil physical properties of puddled rice soils, Tranggono (unpublished data) established that as the paddy aged after a certain stage the bearing capacity increased. In this work it was uncertain whether the increase was due to a soil ageing effect or to the influence of root growth.

In this paper a pot experiment is described in which rice was grown in puddled soil and then flooded or heavily watered, and non-puddled soil heavily watered and also allowed to dry between irrigations. Soil strength was measured as bearing capacity and shear vane resistance.

EXPERIMENTAL DETAILS

The soil used in this experiment is described as a Regosol (FAO, 1974) and was collected from the Mojosari Experimental Station 112° 38'E, 7° 30'S about 45 km SW of Surabaya in East Java, Indonesia. The soil can be classified in general terms as a loam. Prior to preparation of the pots the soil was air dried (water content 5.3% w/w) and ground to pass 2 mm sieve.

The pots used were polythene tubing 10.8 cm diameter and cut into 15 cm lengths. One kg of air dry soil with 200 ml water was prepared in pots by firm packing to a depth of 10 cm giving a dry bulk density of 1.04 Mg m^{-3}. Pots with puddled soil (1 kg soil and 600 ml water) had compacted soil (1.8 Mg m^{-3}) in the bottom. After standing for one day the water and the soil was puddled by mixing with a spatula 20 times. Mixing 20 times in this way gave a puddled consistency similar to a field soil and according to Tranggono (private communication) this is the equivalent of one complete working with plough and harrow.

The treatments used in the experiment were soils with and without plants, the four irrigation treatments were two with puddled soil and two with non-puddled soil:

I1 - puddled soil, kept flooded with water to a depth of 20 mm;
I2 - puddled soil, irrigated each week with 30 mm of water;
I3 - non-puddled soil, irrigated each day with 5 mm water;
I4 - non-puddled soil, irrigated each week with 30 mm water.

Each treatment was replicated four times giving a total of 32 pots.

Rice seeds were planted at ten per pot, after one week they were thinned to five per pot, at two weeks they were thinned again to three per pot, and at three weeks thinned to two per pot.

Measurements of soil strength were vane shearing resistance and bearing capacity. Vane shearing resistance was measured using an Eijkelkamp[3] self recording vane-tester while bearing capacity was measured with a constant speed (electrically driven) laboratory penetrometer speed 0.9 mm/sec with a 1.5 cm diameter plate attached to the measuring transducer. These two sets of measurements were done on day 45 and day 70 after seedling emergence (two days after planting). Water contents were determined at each sampling by weighing the pots. At day 70 the roots were washed and plant height determined.

Statistical analysis was done using a split-plot design the plants and no plant pots being the main treatments and the irrigation treatments being the split plot. A 2^3 factorial was considered as a possible design but because there was only one flooded irrigation treatment (puddled soil) the split plot analysis was preferred.

RESULTS

Values for bearing capacity, shearing resistance and root weight and plant height are presented in Tables I, II and III respectively. The dry treatment I4 was not included at day 45 as the soil was considered too dry because of the sampling day in relation to irrigation time.

[3] Use of this equipment does not imply endorsement of this product.

From Table I it is clear plant roots have a significant effect on bearing capacity the value being as high as 4.8 times the same soil treatment without plants (I2 at day 70). For the other treatments this ratio was about 2.2 At day 70 when roots were washed and weighed there were more roots in treatment I2 than the other three, Table III, and significantly more than in I3 and I4. The ratio of bearing capacity in soils with and without plants on day 45 is smaller than day 70 but I2 has still the largest value of this ratio.

TABLE I

Bearing capacity of soils with and without plants in kPa.

	Irrigation Treatment			
	I1	I2	I3	I4
With plants				
45 days from emergence	59.5	74.8	66.9	-
70 days from emergence	54.8	73.3	118.6	395.4
Without plants				
45 days from emergence	44.8	28.6	41.2	-
70 days from emergence	27.1	15.1	47.9	193.7

Levels of significance

			LSD5%
With plant/without plant (P)	45 days	P = 0.05	7.0
	70 days	P = 0.01	11.3
Irrigation treatment (I)	45 days	n.s.	
	70 days	P = 0.001	22.9
P x I	45 days	P = 0.05	6.6
	70 days	P = 0.01	26.4

Irrigation treatment has no effect at day 45 however I4 was not measured on that day. At the later sampling irrigation treatment is significant I4 having a much larger bearing capacity than the other treatments. There is also a significant interaction between plants and irrigation on soil properties.

The values of water contents showed there was no difference in the I1 and I2 treatments with and without plants, for I3 the difference was 0.5% (volumetric water content) on both sampling days and for I4 the difference was 2.4%. The water contents at day 45 were 32%, 36% and 40.5% for I3, I2 and I1 respectively while at day 70 they were 29%, 31%, 35% and 40.5% for I4, I3, I2 and I1 respectively.

TABLE II

Shearing resistance measured by
shear vane of soils with and without plants in kPa.

	Irrigation Treatments			
	I1	I2	I3	I4
With plants				
45 days from emergence	5.0	5.6	4.7	-
70 days from emergence	2.6	2.6	3.6	10.6
Without plants				
45 days from emergence	3.8	3.5	3.0	-
70 days from emergence	2.0	1.5	2.3	5.1

Levels of significance

			LSD5%
With plants/without plants	45 days	P = 0.05	0.40
	70 days	P = 0.05	0.82
Irrigation treatment (I)	45 days	n.s.	-
	70 days	P = 0.001	0.47
P x I	45 days	n.s.	-
	70 days	P = 0.05	1.16

The shearing resistance of the soil is greater with plants than without plants see Table II. The ratio of plant to no plant averages 1.5 except for the driest treatment where the ratio is 2.1 The differences are significant for with and without plants at 5% on both day 45 and day 70, while for irrigation treatment and plant - irrigation interaction this only applies at day 70.

TABLE III

Weight of roots gm/pot and plant height in cm 70 days after emergence.

	I1	I2	I3	I4	Significance level	s.e.
Roots gm	1.76	2.07	0.92	1.01	P = 0.001	0.15
Plant Height cm	24.4	23.9	21.4	19.8	P = 0.001	0.48

In the wetter soils (I1 and I2) root weight and plant height are larger than the dry soils (I3 and I4), see Table III. Although the final objective of growing plants is yield, larger tops and more roots will in most cases lead to higher yields.

DISCUSSION

The main objective of this experiment was to determine whether soil with and without roots had differences in soil strength and measurements of shearing resistance and bearing capacity have been shown to increase when roots are present. Waldron (1977) has also shown this to occur. However in this experiment the situation was confounded by puddling the soil. Puddling is known to lower shearing resistance Kularatna (1981) and in turn will lower bearing capacity see relationship between bearing capacity and shearing resistance Fig I. Day 70 shows that puddling alone (I1 and I2) gave lower soil strength parameters for both with and without plants however at day 45 the pattern is inconsistent. Looking at the difference in shearing resistance ΔS between with and without plants as done by Waldron and Dakessian (1982) the increase in ΔS due to the presence of roots can be quantified on day 70. If the soils are separated into puddled and non-puddled soil the value of ΔS is larger for the greater root weight even though the difference in root weight is small.

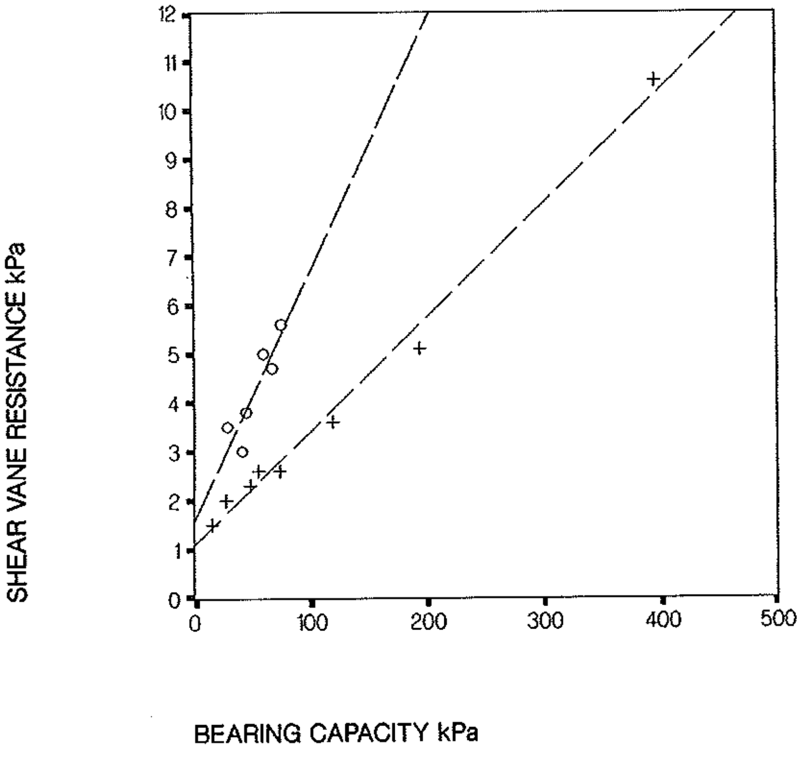

Fig. 1 The relationship between bearing capacity X and shear vane resistance Y on day 45 after emergence (o) $Y = 1.61 + 0.051X$ $r = 0.89$ and on day 70 after emergence (+) $Y = 1.09 + 0.023X$ $r = 0.995$.

In Fig. 1 the linearity of vane shearing resistance-bearing capacity relationship is similar to that obtained by Taylor et al (1966). The ratio penetration resistance (bearing capacity) and shearing resistance for their work was 28:1. In Fig. 1 lines are drawn separately for different days after emergence. The individual correlation coefficients were day 45 - 0.89; day 70 - 0.995 and both greater than the combined coefficient 0.88. The linear relationship confirms that the measured soil properties are related to the basic soil properties of adhesion and cohesion of the soil particles, and indicates that while puddling changes soil strength it does not change the relationship between different measurements of soil strength. Age (or time after preparation) reduces soil shearing resistance and bearing capacity of treatments I1 and I2 i.e. the puddled soil also decreased with age both with and without plants. The strength of the non puddled soil I3 increased with age. Unpublished data (R. Tranggono) shows that bearing capacity of puddled soil increases with time after preparation.

The general increase in bearing capacity with roots in the soil indicates that as rice plants grow in a paddy field the soil is better able to support traffic. However even after day 70 in a wet condition the bearing capacity was less than 95 kPa the pressure usually applied by human traffic (Willatt, 1984). However as the average Asian farmer is physically smaller than the average Western person from which the 95 kPa was determined even if they have smaller feet, there is good reason to expect in the later part of the season good support by the soil is possible. The average pressure applied by cattle is given as between 160 - 190 kPa, this data indicates that it would only be possible to support animals in the dry treatment. Animals are not often used after the rice is planted.

To conclude, roots do increase soil strength and thus as a rice season progresses the soil is better able to support this traffic. In those periods when the soil is drained I2, often the case prior to weeding, strength is greater. Further, in the period while the soil is drained root growth may also be promoted.

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SOIL MOISTURE, SOIL TEMPERATURE AND NUTRIENT EFFECTS IN AN ARABLE LAYER WITH LOOSENED AND COMPACT ZONES

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ABSTRACT

A new concept of the arable layer is presented. The zoning approach and its functioning is described. It was found that soil porosity had the biggest effect on soil moisture, soil temperature and nutrient availability. A comparison was made with other types of arable layers and the significance of the zonal approach is discussed.

INTRODUCTION

Since 1975, research is carried out by the authors in four counties of Heilongjiang province, with typical weather and soil conditions (semi-arid climate with cold winters, black soils), on physical and chemical soil properties, on the activity of soil micro-organisms and on growth and yields of crops. Basically, three types of arable layers were compared: the zonal layer, a fully loosened layer and a fully compact (non-disturbed) layer. Main emphasis will be given here to the zonal layer concept.

METHODS

Three different arable layers were created. The zonal system by chiseling to a depth of 30 cm, with the tines of the chisel plough spaced at fixed intervals of 70 cm. The loosened field was made by mouldboard ploughing to a depth of 20 cm, whereas the compact field can be considered as the result of a no-tillage system, with crops sown by direct-drilling equipment. Plot size for each treatment was 50 x 70 m^2, with 10 m wide borders. The experimental plan followed a randomised block design with at least three replications. Soil moisture content was determined gravimetrically, soil temperatures were measured with adapted mercury thermometers. The soil micro-organisms were counted after growing cultures on plates or in tubes. The nutrient content of the soil was determined by conventional laboratory methods.

RESULTS AND DISCUSSION

The influence of the soil tillage method on soil moisture, temperature and nutrients by altering the structure of the arable layer.

In the nineteen-sixties, much attention was paid to the improvement of soil tillage systems, which led in the seventies to the introduction of new tillage methods. Major emphasis was given to the constitution of the arable layer, as this presents the layer through which the biggest effects can be obtained.

The tilled soil layer is essential in determining the soil fertility and crop yields.

The soil condition in the tillage layer on the one hand has an effect on the rooting system of the plant and thus influences crop growth, and on the other hand affects the decomposition of organic matter and subsequent release of mineral nutrients by microorganisms, as well as the formation of stable humus. Both effects determine largely the soil fertility. These tillage-related soil conditions do have an effect on the final crop yield and thus may be partly responsible for economic benefits. A diagram showing the relationships is given in Figure 1.

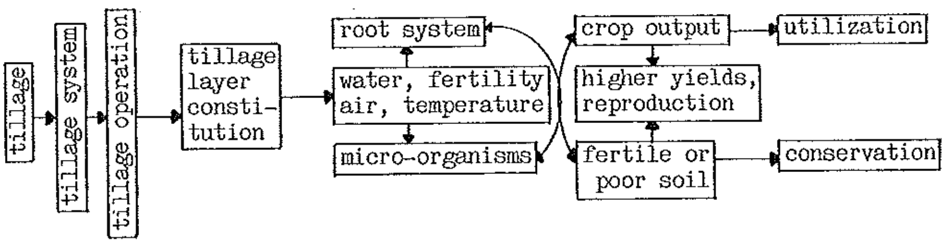

Fig. 1. Diagram showing causality relations affected by soil tillage.

A basis for the evaluation of a tillage method should be the resulting constitution of the tilled layer. The choice of tillage equipment should also be guided by this evaluation. Thus, the determination and creation of the "optimum tillage layer", serving the needs dictated by the local conditions, is the most important, but also the most difficult task of soil tillage.

The new concept of the tillage layer constitution and its functioning.

The tillage layer consists of tilled soil and surface material, i.e. the bottom, center and surface soil layer and the above-surface material. Since any of these components may have many different appearances, there should always be available a certain combination of these components to suit specific weather, soil and topography conditions. The tillage layer is, together with the subsoil, responsible for the growth and yield of the crop.

The influence of the soil porosity on moisture content, temperature and nutrient availability.

Direct porosity effects.

Since 1979, experiments were carried out using five tillage treatments causing porosities of 39, 46, 53, 60 and 67 per cent in the tilled layer. In Fig. 2, the effect of total porosity of this layer on a large number of soil and soil-related characteristics is given.

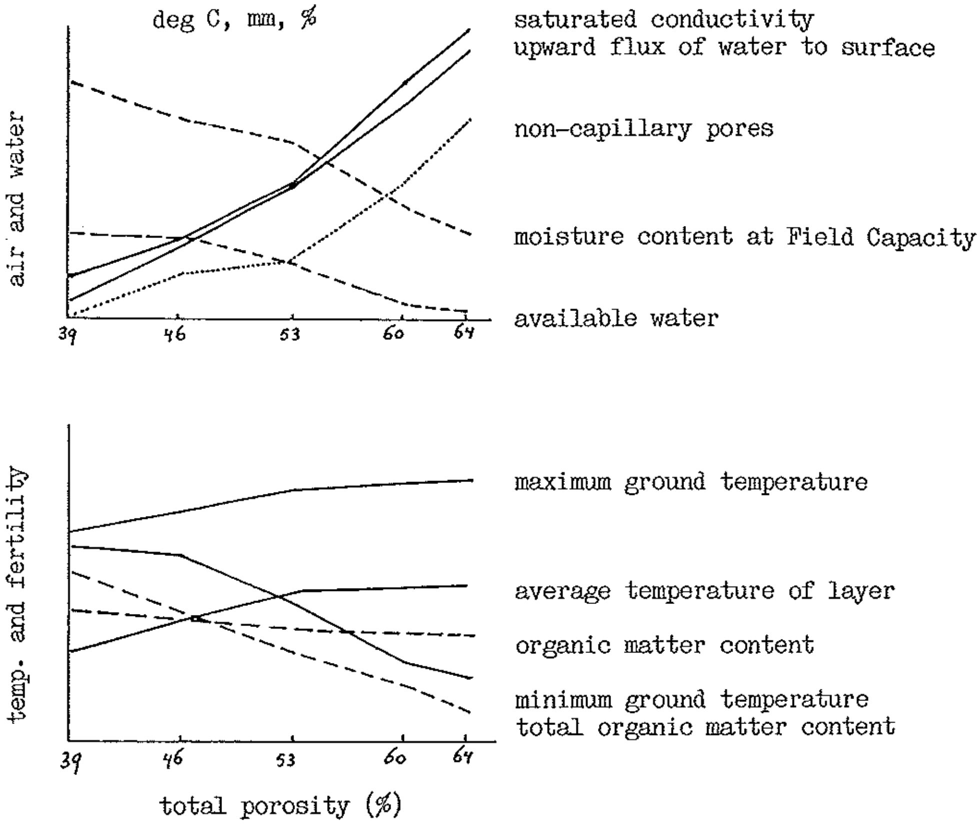

Fig. 2. Effect of total porosity on moisture, temperature and nutrient-related soil characteristics.

Soil moisture.

In the 30 cm toplayer, the difference in available moisture between lowest and highest porosity (difference 28%) was 31.2 mm, with a variance of 49%. The difference in moisture at field capacity was 80.5 mm (var. 66%). Difference in saturated conductivity was 22.3 mm (var. 86%).

Temperature.

In the same 30 cm layer, difference in maximum soil temperature was 4.6 deg. C (variance 9%) between lowest and highest porosity. The difference in average daily temperatures was 5.7 deg. C, with a variance of 18%. At 50 cm depth, the following differences were measured: average temperature 0.3 deg C, maximum temperature 0.7 deg C, minimum temperature 0.3 deg C, daily temperature wave 0.6 deg C. Variances for these values were 2,4,3 and 9% respectively.

Nutrients.

The differences in organic matter content, total nitrogen en total phosphorus between lowest and highest porosity were 0.2%, 0.007% and 0.008%, with variances of 7, 16 and 6% respectively.

The effect of a zonal tillage layer on moisture, temperature and nutrients.

The zonal tillage layer has a very positive effect on a number of important characteristics. Available moisture, water permeability and organic matter content are respectively 4.5, 13.5 and 5.5% higher in a zonal system compared to a completely loosened layer. Compared to a completely compact layer, these values are respectively 5.6, 40.2 and 1.6% higher in the zonal system. Over twelve years of experiments with these tillage systems, the yields under the zonal tillage system were 7.2% higher than under the loose-soil system, and 11.2% higher than under the compact-soil system. We will therefore discuss these systems in more detail.

The zonal tillage system.

Tillage zones are achieved by loosening only part of the field, thus creating strips of loosened soil, alternating with strips of undisturbed soil. Fig. 3 gives a cross-sectional view of such a tillage system.

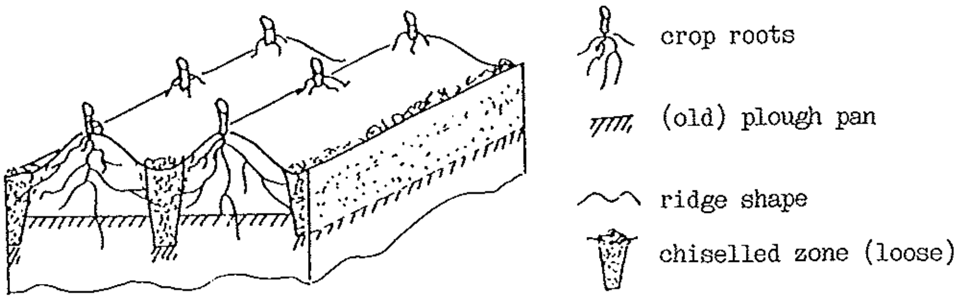

Fig. 3. Diagram showing the zonal tillage concept; loosened furrows and undisturbed (compact) ridges.

The effect on the soil characteristics.

Movement and distribution of water in soil with adjacant loose and compact zones is different from that in either entirely loose or entirely compact soil (see Fig. 4a); with a markedly different distribution between loose and dense soil of the tillage zones (Fig. 4b).

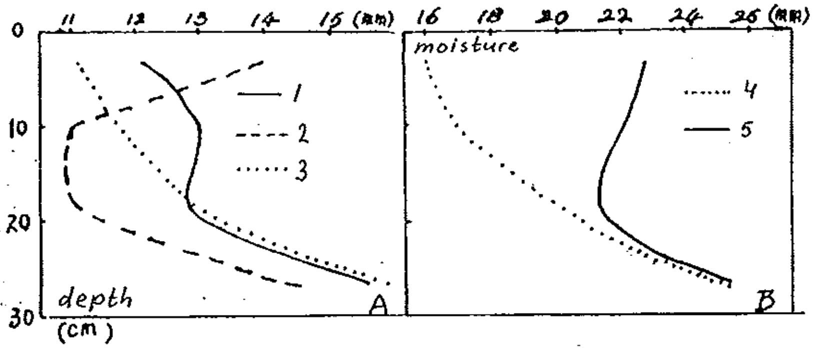

Fig. 4. Moisture distribution in the top 30 cm of the profile: 1 = zonal system, 2 = entirely loose, 3 = entirely compact, 4 = loose section in zonal system, 5 = compact section in zonal system.

The temperatures in either loose or dense section of the zonal tillage layer are significantly different from the temperatures in entirely loose or dense layers (see Fig. 5). A major cause for these temperature differences is the different moisture distribution. The temperature differences will cause a transfer of heat between the layers.

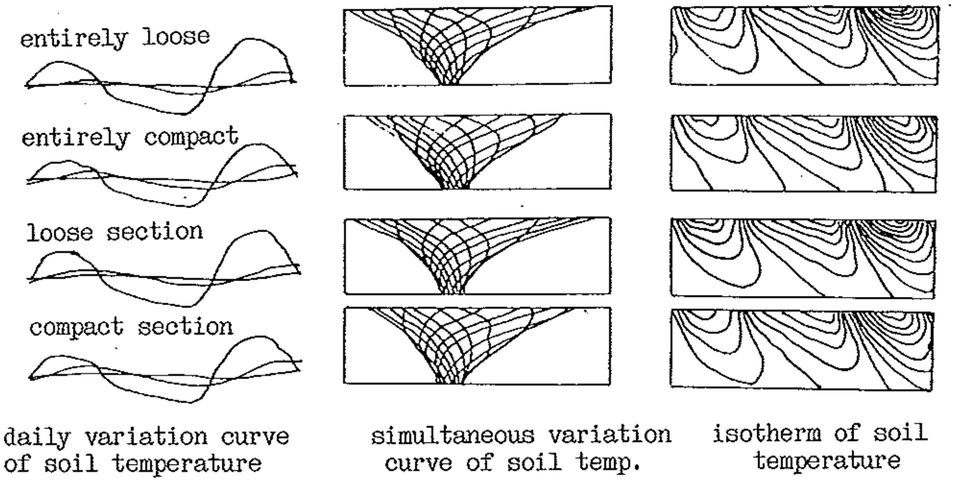

Fig. 5. Three different temperature-wave curves.

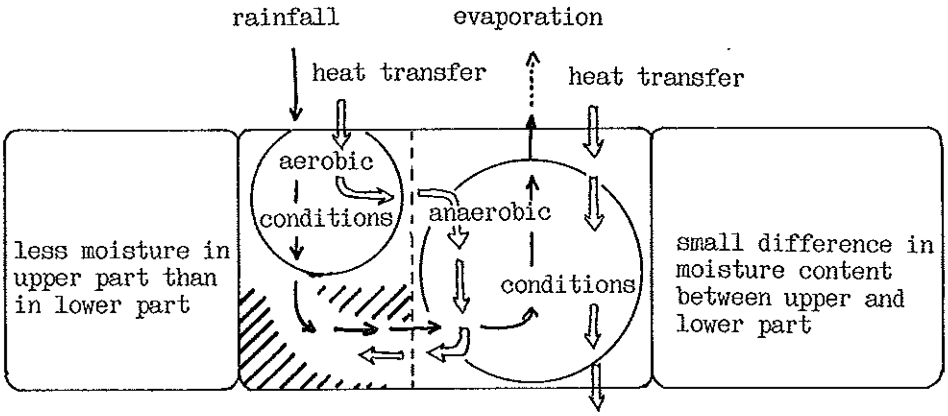

Fig. 6. Moisture and heat movement in the compact layer.

Fig. 6 shows schematically the movement of moisture and heat in the zonal tillage layer.

A very important characteristic of a zonal tillage layer is the co-existence of aerobic and anaerobic decomposition. This has a major effect on the nutrient status of the soil. The number of aerobic micro-organisms increases by 19 to 130%, the rate of nitrification, ammonification and phosphorus transformation is increased by 50 to 105% in the loose section. In the compact section, the number of anaerobic micro-organisms increases by 24 to 39%, the rate of denitrification by 23%. Experiments showed that the total nutrient content in the loose section is 3 to 11% less than that in the compact section.

It should be pointed out that the activity of the aerobic processes in the loose section of the zonal system is 40% stronger than that in an entirely loose layer with comparable porosity. On the other hand, the intensity of the anaerobic process of the compact section in the zonal tillage system is 50% stronger than in a comparable entirely compact layer. When taken as a whole, the intensity of the biological processes in the zonal tillage system never exceeds that of either two of the full-field systems (see Table I).

Table I. Number of aerobic cellulose-decomposing bacteria in different soil structures.

structure	entirely loose		loose/compact		entirely compact	
section	furrow	ridge	furrow (loose)	ridge (compact)	furrow	ridge
nr. of bacteria per g of dry soil	3220	7137	5380	2231	2656	4419
total	10357		7611		7075	

It can be concluded that using appropriate tillage techniques, in our case the formation of tillage zones, may be an effective means to regulate the nutrient availabilty to the crop.

SECTION 2

CROP AND SOIL RESPONSES TO WHEEL TRAFFIC

SOIL COMPACTION : ANALYSIS OF FIELD AND LAB EXPERIMENTS

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ABSTRACT

To complete the diagnoses on the ill-effects of soil compaction on crops with referential data on the compaction due to agricultural machinery , we have develop a methodology for the analysis of soil physical state after passages of the tyres.We use an automatic scanner penetrometer and an experimental "compacting wheel" wich permits us to test different types of tractor tyres.

INTRODUCTION

Modern cropping systems are based on agricultural machinery and this machinery is reponsible for most of the soil compaction. Since several years CEMAGREF elaborate a referential system for the compaction of agricultural soils. The aim is to complete the diagnoses on the ill-effects of soil compaction on crops with referential data on the compaction due to agricultural machinery, setting up of referential criteria (soil, passes of implements, tires, load) and defining the usual conditions of agricultural operations. We want to collect the basic information for advising farmers and manufacturers on the effects of dimensions and positioning of different tires on soil conditions.

For that reason we have develop an accurate methodology for the analysis of soil physical state after the passage of the tyre in order to study the influence of tyre characteristics on the soil compaction.

1 - Material used

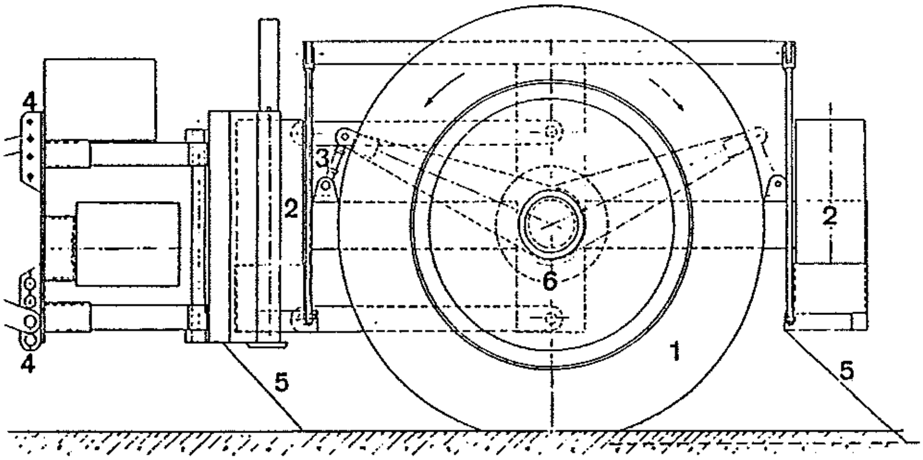
We have tested that methodology in different sort of soils (a sandy and a clay loam soil). We used for that purpose an experimental "compacting wheel" and special measurement equipments.

The experimental "compacting wheel":

Permits us to test different types of tyres. It can be fitted with tyres of varying diameter and width : from front tyres of four wheel drive tractors to dual tyres. The wheel tested is driven by an hydraulic motor which, is activated by the p.t.o of the tractor. It pushes the tractor. We measure the torque applied to the wheel axle with a force transducer placed at the end of a one meter long arm, hydraulic motor been monted in balance.

The system for wheel speed measurement consist of a magnetic pick up placed over a rotating iron gear.So we have the theoretical speed needed for determination of wheel slip of the drive wheel. The real wheel speed, the forward speed, is measured by using a photo electric transducer fitted on the tractor chassis . Barriers spaced equally at 5 cm distance along the test bed are used to intercept light from an emitter. The frequency of impulsions produced is proportionnal to forward speed.

It is possible to increase the load on the tyre by adding till 6 half-ton masses. So the total load varies from 1,500 kg to 4,500 kg.



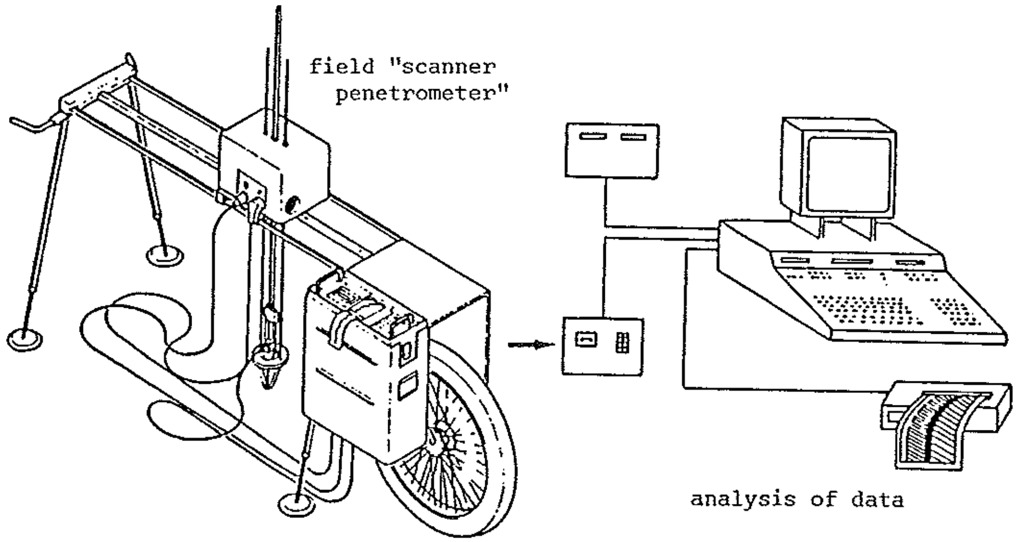
Experimental "compacting wheel"

1.Tested tyre
2.Additional load
3.Axle torque measurement
4.Pushing action Measurement
5.Measurement of the rut depth
6.Slip measurement

Special measurement equipment

We use a scanner penetrometer an automatic device developped at CEMAGREF . From a serie of penetration tests (strength and depth) recorded on a magnetic tape, an accurate survey of the soil surface level and of the hardness of the different soil layers, in the plane perpendicular to the soil surface and crossing the rut, can be done. A printer draws a graphical scanner type representation which helps to study the extent of the soil compaction, the extension of the compacted area and the profile of the rut.

To complete penetrometer measurements, we use the LPC-INRA gamma ray densitymeter in the bottom of the rut. So we obtain a density profile. Such measurements are used to correct the effect of the soil moisture changes on the penetration resistance value.



2 -Experimental process

The preliminary step in field testing is the preparation of test bed :in a first time we used to plough the land and after,to till it by a rotary cultivator to break clods. So we obtained a 30 cm layer of loose soil.Now we use a rotary spading machine at a working depth of 40 cm, with two passages we obtain the homogeneous deep layer required.

During the tests the wheel is placed in the centre of the test bed. Following, the barriers are placed along the lenght of the test bed .Once the different wheel and measure adjustments are verified, the tractor heads on the test bed at constant speed and passes the first barrier with axle torque zero.Then the wheel axle torque is increased gradually when the tractor passes along the others barriers .The test operator, inside of the tractor cabin, controls the increase of axle torque and monitors the outputs from different transducers. The signals are transferred to a test car through a telemetric system of data acquisition and are recorded on a sixteen channels tape recorder for subsequent analysis. The different parameters measured are : axle torque, forward speed, wheel speed, pushing action on tractor linkage (six components) and soil surface level before and after wheel passage measured with ultrasonic transducers.

At the end of the dynamic phase-state, observations and measurements are done on the soil to analyse the effect of drive wheel passage.First it is necessary to find out accurately the compacted site corresponding at the choosen value of the axle torque. We use a UV paper plotter for a continuous record of the axle torque and the impulsions from the photo electric transducer.

As soon as the test run was over, the choosen sites of the compacted test bed are covered with plastic sheets in order to minimise soil moisture losses and at the same time to prevent infiltration of the rain into the soil. The plastic covers are removed at time of penetration test. The soil resistance is measured up to a depth of 50 cm and at each millimeter along the vertical penetration. The distance between two penetrations is 2 cm with the cone of 0.25 cm2 section used for the penetration test .

Just after penetration measurements, in the same vertical plane, we measure the bulk density and take soil samples for the moisture content determination.

3 - First results and discussion

We compared several types of tyres in different conditions of use : variing load, axle torque and inflation pressure.

The investigations with the soil penetrometer and the gamma densitymeter confirm the results of the precedent studies on soil compaction.

1. Influence of the wheel load : The extent of the soil compaction increases with the increase in the wheel load. At hight loads the compaction effects are severe and go up to a great depth.

2. Influence of the contact area of the tyre with the soil:The contact area depends on the tyre specifications, inflation pressure and wheel load. For a great contact area more soil volume underneath the wheel is subjected at a given load, thus minimizing the compaction effects.

3. Influence of the axle torque:The extent of the soil compaction is greatly influenced by the wheel axle torque. Up to a certain limit the soil resists the applied torque and thus top soil layers are compacted.After,this increase in the axle torque causes a complete shear off,the top soil leaving no strength .

Discussion

The success of the methodology of comparison proposed depends upon some factors to be controlled during tests : selection of the test field, control of various soil parameters.The field selected for compaction studies should have homogeneous soil texture andstructure on enough depth (40 cm). This is of a great help to reveal the all compaction effects.

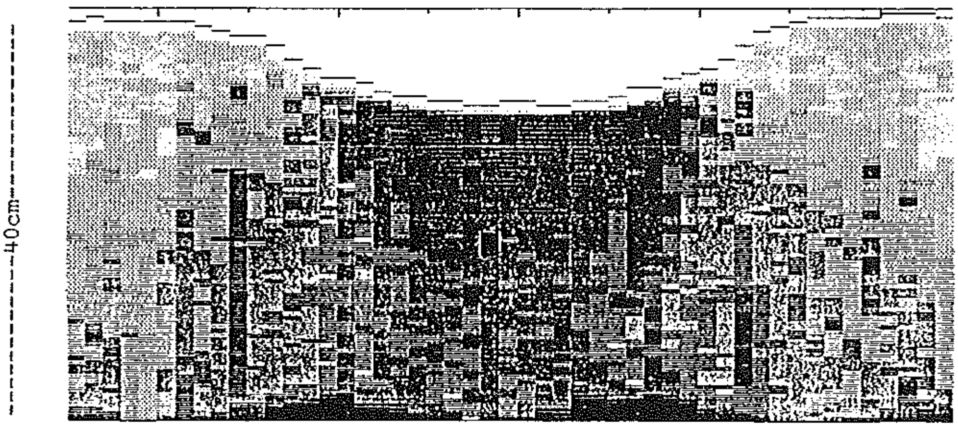
As regarding the type of soil we firstly choose a sandy one because it seams more easy to prepare in order to create homogenous structure conditions.Yet its cohesion is not very high and sometimes not sufficient to study compaction effects when low loads and high axle torques are concerned.So we work in a soil bin containing clay loam soil.

Among soil parameters, moisture content plays the main role. It will have effect on the extent of compaction during the wheel passage, and on the penetration measurement too. So maximum efforts should be made to bring homogenous soil moisture content .

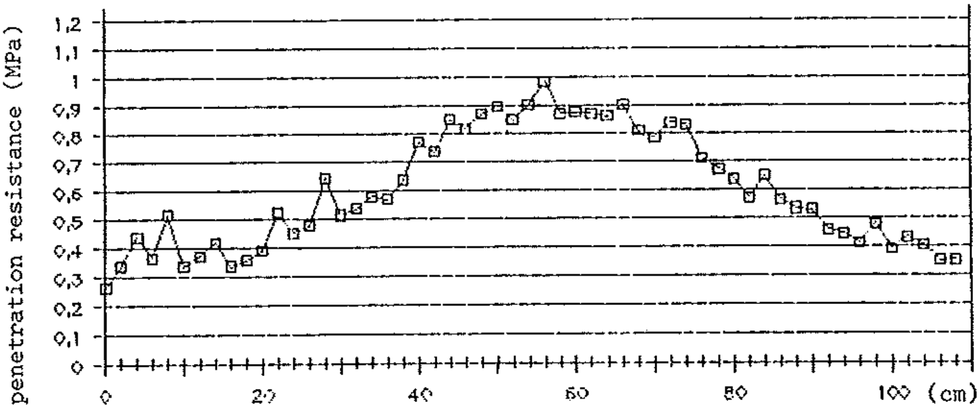
For all that risks of non homogeneity of the test bed it seams necessary to carry out penetration measurements on the same place before and after the passage of the wheel. That is possible, such a penetration test is not a destructive one and preserves the soil structure.

We use it very often ,not only on test bed but also in normal agricultural conditions.This is a very efficient methodology much appreciated by farmer's advisers.

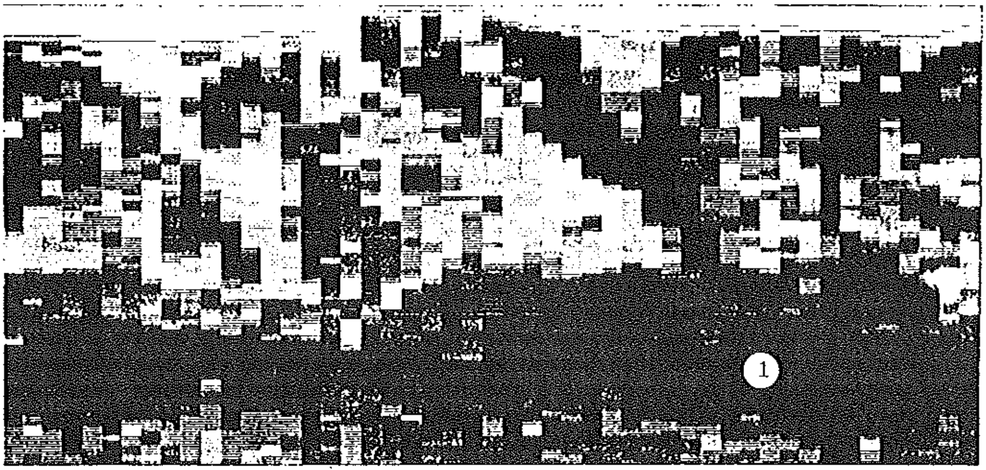
EXAMPLES   PENETRATION PROFILES



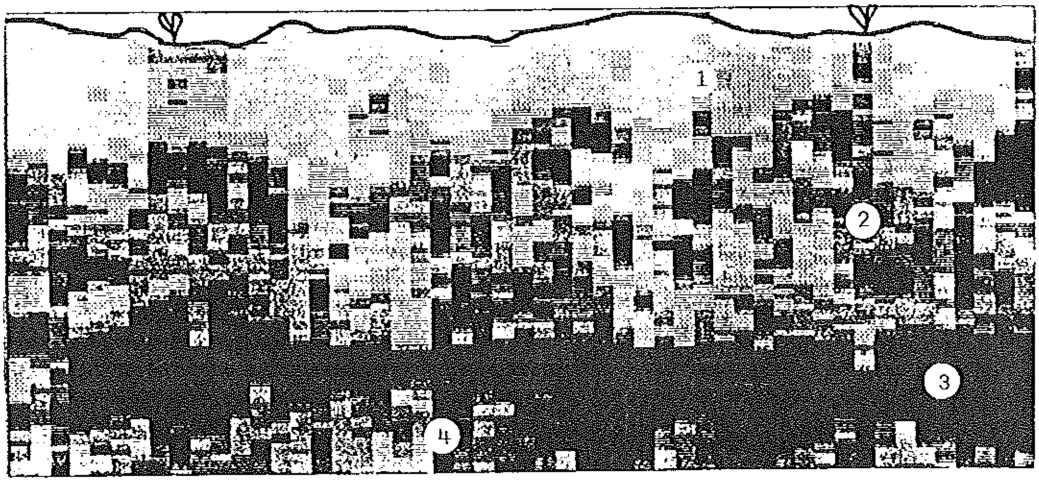
Compaction after a passage of a 18.4R38 tyre with 750 daNm axle torque.



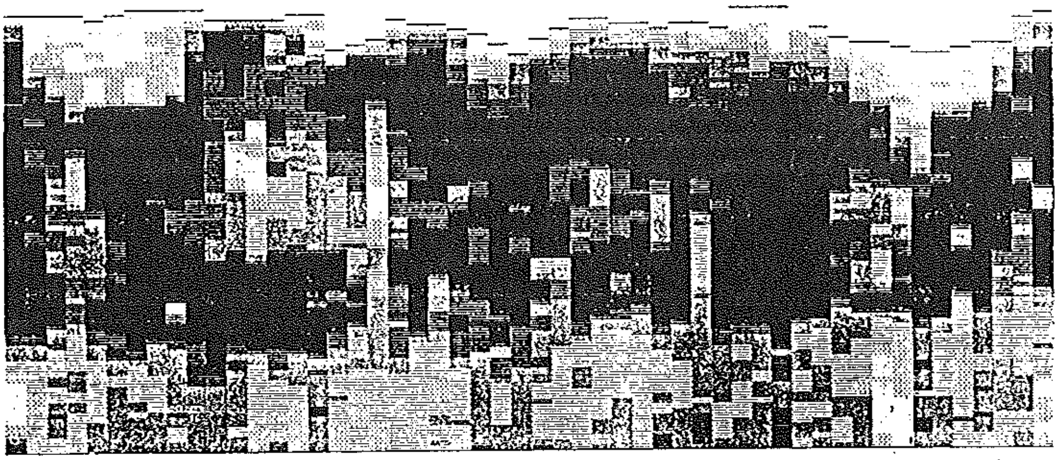
Mean value of the penetration resistance (from 10 to 40 cm depth)



Deep compaction on a bad drained silty soil :(1)a thick plough-pan



Different grades of soil compaction in a soil preparation for maïs
(1) seed bed ; (2)ploughed layer ; (3)plough-pan ; (4) subsoil.



Compaction of the upper layer in a direct-drilled system (since 10 years)

THE INFLUENCE OF SOIL GEOMETRY ON SOIL COMPACTION UNDER WHEELS

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ABSTRACT

Many methods of amelioration of duplex soils allow soil geometry to be modified. Geometry of the two layers in the profile can be altered by deep tillage into the lower layer. The geometry of the fragments produced by tillage can also be affected. Biological activity can form biopores in the new soil. These changes in soil geometry can either lessen the stress experienced by the soil or improve the ability of the macrostructure to withstand stresses. The consequences for soil management are that if deep biopores are formed and the optimum shapes of the cross-sections of zones of deep tillage can be selected, then there may be considerable enhancement of the longevity of amelioration. This improved knowledge of the effect of soil geometry can be used to improve numerical models which currently simplify soil macrostructure to a point that is especially inadequate for the ameliorated duplex soils in Australia.

INTRODUCTION

Numerical models are increasingly used for soil compaction and tillage research. "We are extremely fortunate to be involved in tillage research at this time. Never before have we had the modelling techniques and computers available to attack such complex problems" (Larson and Osborne, 1982). However, the accuracy of prediction of such models is only as good as their design allows. Most have simplified soil structure to ignore macrostructure and multilayered soils with non-planar boundaries (e.g. Blackwell and Soane, 1981). Our current level of understanding lies between such simplified soil structure and the real conditions. This paper attempts to clarify the influence on stresses and deformations of the soil by one larger scale expression of macrostructure, biopore channels, and the effects of deeply cultivating two-layer (duplex) soils. In the longer term such influence could be included in, if not derived from, more accurate numerical models.

Duplex soils used for irrigation in Australia can limit crop yield by a dense, impermeable clay B horizon (Cockroft and Martin, 1981). Long-term amelioration appears easier if the B horizon is initially disrupted by deep dultivation and the addition of a suitable ammendment, such as gypsum, to restrict dispersion and swelling of the sodic clay. Compaction of the ameliorated soil below the depth of normal cultivation can diminish the period for which the improvement is effective, and therefore the economic value of the amelioration. Thus the effects of wheels over such improved soil needs to be well understood. Deep cultivation can have the following effects on soil geometry-1. different cross-sectional geometries of the A/B boundary after localised tillage, e.g. triangular, by single rip lines and rectangular, by gypsum enriched slots. 2. Different shapes of the fragments of B horizon produced by deep cultivation methods, e.g.

coarse angular blocky by ripping and smaller, platy 'flakes' by slotting. The shapes of the cross-sections and fragments have been described by Blackwell et al. (1987) and Jayawardane et al. (1988). The narrower, rectangular slots allow smaller vertical stresses on the loose soil within them, as well as less structural change, than do the wider, triangular ripping troughs, during transverse wheeling (Blackwell et al., 1988b). It is unclear what effect the geometry of the cross section and the geometry of the clay fragments have on diminishing such stresses and deformation of loose soil in the slots. Edge-to-face packing of the platy clay fragments in the slots may allow the stresses to bridge the finer soil between the fragments and diminish the loss of macroporosity.

Transverse wheeling transmits less stress to the soil in the slots than longitudinal wheeling (Blackwell et al., 1988a). An effect of the shape of the cross-sectional geometry can be illustrated from the results of Blackwell et al. (1988a) by deriving emprical ratios of the stresses in and outside the slot and the dimensions of the slot and type (Fig. 1). Thus optimum ratios can be used to choose most appropriate tyre dimensions for a known slot, or vice-versa.

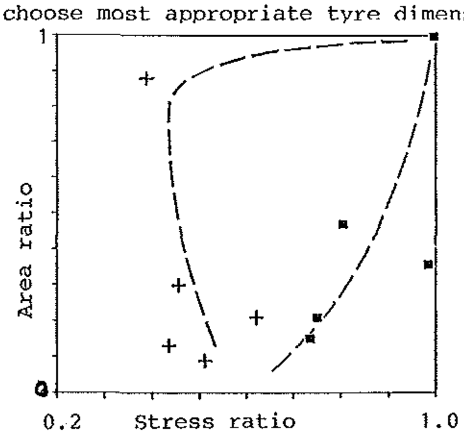


Fig. 1. Stress ratio (max. vertical stress in the slot/adjacent to the slot) and area ratio (area of the wheel contact area over the slot/total contact area) at 20cm depth for slots of different width during transverse (+) or longitudinal (■) wheeling of slots of different widths.

Horn (1986) has reconised the influence of the orientation of the geometry of macrostructure on stress transmission in real soils. Biopores are an extreme example of large, vertically orientated pores. Such preferential avenues for root growth can considerably influence the growth and yield of grain crops (Jakobsen and Dexter, 1988), thus their survival of wheeling effects is important.

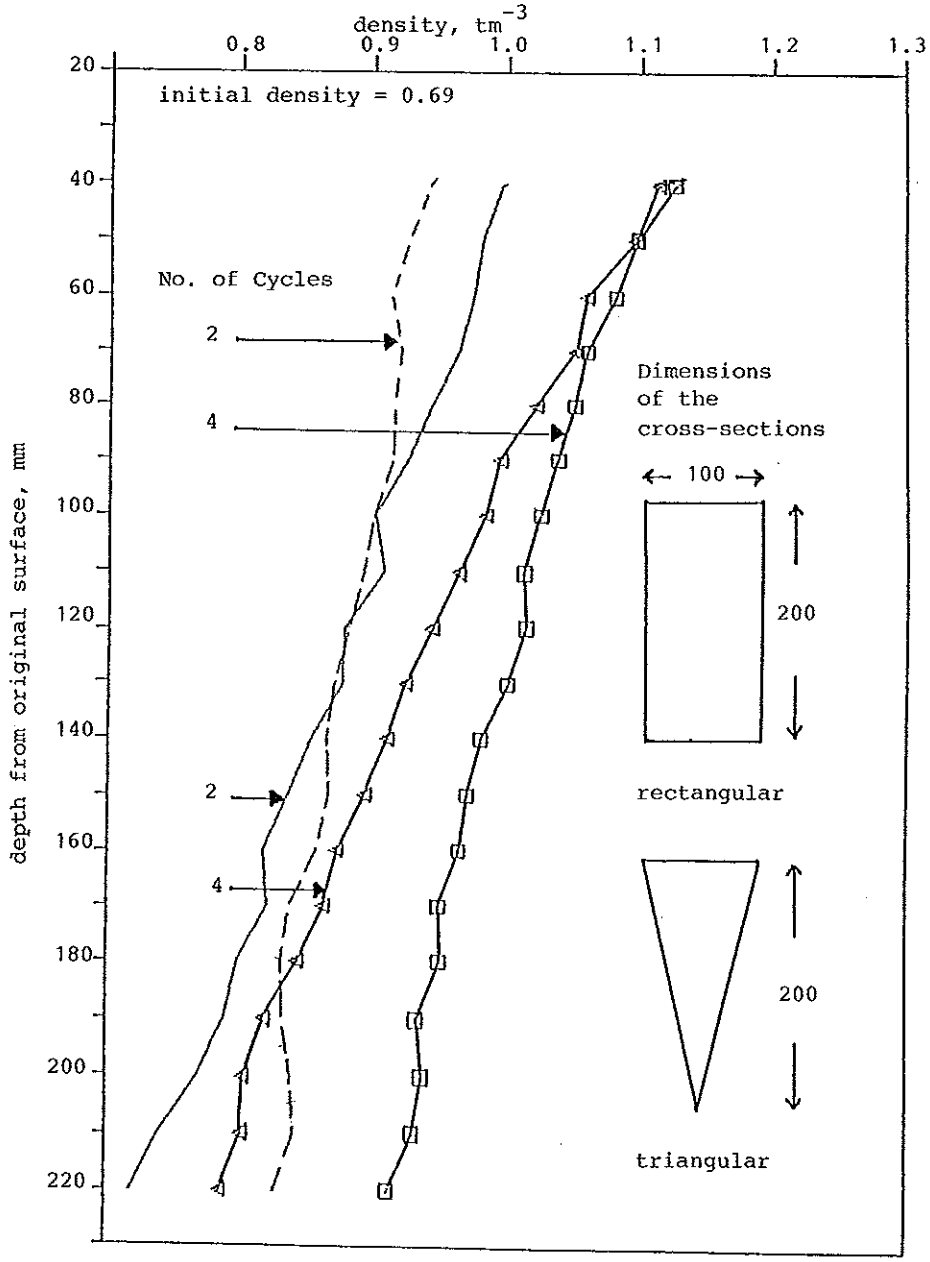
This paper outlines some results from two groups of experiments which aimed to -

1. identify any difference between the compaction of loose soil in zones with a simple rectangular or triangular cross-section; and
2. identify uniaxial loads needed to close biopores.

METHODS

For the shape of the cross-section, homogenised aggregates, <2mm diameter, from an ameliorated transitional red-brown earth (Table I) were loosely packed at 16%w/w water content in boxes with rectangular or triangular cross-sections (Fig. 2). The movable upper plate of each box was loaded to the equivalent of 100kPa for one second. In the field,

Figure 2. Soil density profiles in boxes with rectangular (□) or (◁) triangular cross-section after two or four cycles of loading. The dimensions of the cross-sections are indicated in mm.



settlement of the parts of the tyre not over the slot would be limited by the strong subsoil beneath the loose topsoil. The soil used for the experiment compressed 56% under 100 kPa uniaxial loading. Therefore in the experiment maximum vertical travel of the top plate was limited to 56% of the scaled-down topsoil depth (i.e. 30mm). The loading cycle was repeated up to four times for each box and loose soil added to the top between each cycle to imitate cross-cultivation between wheelings. Before and after each cycle soil density was measured along vertical transects by gamma-ray transmission. Transects were made along the centre-line of the box and at 10mm intervals to the edge.

Table I. Physical properties of the soils

type	p.s.a. % sand	silt	clay	OM %	clay minerals	ex. Na %
Lemnos loam B hz	22	30	47	0.4	kaolinite dominant	6.0
Ameliorated TRBE*	44	16	40	1.3	kaolinite dominant	1.5

* transitional red-brown earth, CIFR research site, Whitton, NSW.

For the biopores, soil cores with or without biopores formed by taproots of lucerne (Medicago sativa) were cut from an ameliorated red-brown earth (Table 1), Lemnos loam at Kyabram, Nth Victoria. After equilibration to -10 kPa water potential they were loaded uniaxially for 30 sec with 100 kPa, they were then re-equilibrated at -10 kPa. Air permeability was measured by a constant rate method at -10 kPa potential before and after the loading.

Artificial biopores were made by pushing sharpened rods (1, 2 or 5 mm diameter) along the axis of cores of the same homogenised ameliorated soil used previously (Table I) after preconsolidation to 50 kPa at -3.5 kPa water potential. Cores with or without artificial biopores were loaded uniaxially for 30 seconds in steps from 50 to 400 kPa. Air permeability and volume was measured before and after each loading step.

RESULTS

The cyclic loading of the boxes with different cross-sections increased the density less in the box with triangular shape than in that with rectangular shape (Fig. 2). There was also a suggestion of a more rapid increase of density at the bottom of the triangular box, between the second and fourth cycles, than at the bottom of the rectangular box.

The soil with real biopores retained more permeability after loading than the soil without them (Table II).

Table II. Air permeability at -10 kPa water potential for soil cores with or without biopores from lucerne taproot channels, before or after uniaxial loading for 30 sec at 100 kPa.

	air permeability, μm^2 before	after	% change
with biopores (2-5mm)	22	10	-55
	LSD P <0.05= 9		
without biopores	3	1	-67

The response of the artificial biopores to loading was initially analysed as the load required to bring the cores to an air permeability just less than an arbitrary value (85 μm^2). This showed (Table III) that the channels >2mm remained open for loads up to 400 kPa and channels of 1 mm were restricted by the same stresses.

Table III. Uniaxial load for an air permeability 85 μm^2. (kPa)

diameter, mm	0	1	2	5
(vertical channels)	150	200	*	*

* = >400 kPa, channel not closed.

DISCUSSION

The loose soil in the boxes was compacted less at depth using a triangular cross section because a component of the side-wall friction would provide upward reaction into the soil and develop an 'arching' effect which would lessen the stresses applied to the deeper soil. Such reaction would be less from the vertical sides of the rectangular box. This effect should be increased by increasing the friction between the soil and the wall and/or making the interface more irregular. Thus localised tillage zones into the B horizon, of the same width loosened soil if they are of triangular, rather than rectangular, cross-section. The previous observations of the loose soil within ripping troughs compacting more easily than soil within slots of rectangular cross section (Blackwell et al., 1988b) can be explained by the larger width at the top of the B horizon of the ripping trough than the slot. Thus more force from the wheel is applied to the contents of the trough than the slot. However there is a concern for triangular cross-sections. Figure 2. suggests that repeated loading and pushing in more soil causes a 'congestion' of material moving to the bottom, or 'point' of the cross-section. Optimum depths and angles may be available which minimise increased compaction at the bottom of a 'trangular slot'.

Biopores wider than 2mm are clearly very difficult to close by uniaxial stress. In ameliorated subsoils stresses from wheels are mostly compressive, and rearely above 200 kPa. Thus such biopores should easily survive at these depths. Nearer the surface there are more shear forces from wheels, which should close biopores more easily.

CONCLUSIONS

Slots with triangular cross-section and/or roughened, irregular sides and biopores >2mm diameter should enhance the longevity of the amelioration of irrigated duplex soils. Such effects of soil geometry need to be included in numerical models of the compaction of such ameliorated soil.

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INFLUENCE OF PLOUGHING, ROTARY CULTIVATION AND SOIL COMPACTION ON MIGRATORY PLANT-PARASITIC NEMATODES

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ABSTRACT

A series of three experiments at two sites were conducted to investigate the effect of ploughing, rotavation and compaction on migratory plant-parasitic nematodes in eastern Scotland. Ploughing had no detectable effect on nematode numbers while rotavation and compaction differentially reduced the numbers of all plant-parasitic species. The differential effect of both rotavation and compaction may reflect the interaction of a number of soil factors and characteristics associated with individual nematode species. Cultivation kills relatively few nematodes compared with chemicals and cannot be considered as a practical alternative for nematode control. However, in Scotland where nematode multiplication is slow even the few nematodes killed each year by cultivation may contribute to the lower numbers of nematodes recovered from intensively cultivated agricultural soils compared with populations under permanent pasture or long term leys.

INTRODUCTION

Migratory plant-parasitic nematodes are small (0.2 to 1.0 mm long), thin, delicate worm-like animals which live in the film of water usually found around soil particles and between soil aggregates (Wallace, 1958; Jones et al., 1969; Boag and Robertson, 1983). Unlike cyst nematodes which persist in the soil for most of the year in their protective cyst, migratory plant-parasitic nematodes are particularly sensitive to mechanical damage (Bor and Kuiper, 1966; Brown and Boag, 1988).

Corbett and Webb (1970) compared the effect on nematode populations of ploughing and direct reseeding with wheat and found that the reduction in numbers due to ploughing varied between sites and between nematode genera. Evans (1979) also reported considerably lower populations of Longidorus leptocephalus in plots ploughed and reseeded with grass each year compared with populations in plots left as a long-term ley. Similarly Boag and Geoghegan (1984) recorded a 55% reduction in L. elongatus numbers after a long-term ley was ploughed and reseeded with grass for four consecutive years. Oostenbrink (1964) found a single pass by a rotavator reduced the numbers of Paratrichodorus teres by 61% compared with harrowing while Boag (1983) found rotavation differentially killed a range of plant-parasitic nematode species. The effect of compaction on nematode numbers and the yield of crops is less well understood. Whitehead et al. (1971) were able to demonstrate increased plant growth occurring in the compacted tracks due to tractor wheelings in sugar been fields where Docking disorder due to nematode damage had occurred. The reason for the increased growth may have been due to compaction killing the longidorid and trichodorid nematodes or as suggested by Jones et al. (1969), compaction reduced the pore space between the soil particle and hindered nematode movement. Compaction due to tractor passes have indicated that the nematode numbers were significantly reduced to a depth of 15-21 cm below the wheel markings and that a range of nematode species were differentially killed (Boag, 1985).

The present paper reviews the effect of mechanical cultivation of soils on migratory plant-parasitic nematodes and considered the impact cultivation has on the size of both beneficial and harmful nematode populations.

MATERIALS AND METHODS

A series of experiments on the effect of cultivation on migratory plant-parasitic nematodes were conducted at two sites in eastern Scotland. Site 1 was at a forest nursery near Scone, Perthshire where the predominant nematode species was Rotylenchus robustus while site 2 was at the Scottish Crop Research Institute, Invergowrie where a range of nematode species were present.

The effect of ploughing on nematode numbers was investigated at both sites by taking ten, 5 cm diameter by 10 cm long cores of soil from each of the following depths 0-9, 10-19, 20-29, 30-39 and 40-49 cm prior to and immediately after ploughing. The single furrow plough was set at a depth of 20 cm and pulled at a speed of approximately 2.5 km/hr. The effect of rotary cultivation was also investigated at both sites using twelve plots (4.5 m x 2 m) divided by guard areas 2 m wide. Five composite soil samples were each made up from five sub-samples from different areas of each plot before and after sixteen passes of the rotovator. Single composite samples were also taken after one, two, four and eight passes. Rotavation was at 172 revolutions per minute at a tractor speed of approximately 2.5 km/hr using L-shaped blades to a depth of 20 cm. The influence of compaction on nematode populations was studied at 0-7, 8-14 and 15-21 cm depths from ten sampling stations in a line 1 m apart. A tractor (weight 2824 kg; rear type diameter 1.35 m and width 34 cm; front type diameter 1.01 m and width 28 cm) was driven four and eight times over the line of stations at approximately 2.5 km/hr. Soil samples were taken before and after the fourth and eighth passes.

Nematodes were extracted from the samples using a modification of a sieving and decanting technique (Boag, 1974) and then stored in triethanolamine formalin (TAF) before being identified and counted using a low powered binocular microscope.

RESULTS

The texture of the top 20 cm of soil at both sites was classified as a sandy loam, the greatest difference being the amount of organic matter; 6% at site 1 and 12.5% at site 2. The predominant plant-parasitic species at both sites were not significantly affected by ploughing, the mean R. robustus population in the top 20 cm being reduced by only 2.5% while the comparable figure for L. elongatus was 2.0%. These figures were within the variability in nematode numbers recorded from below the plough depth (Table II). A single pass of a rotary cultivator reduced R. robustus and L. elongatus populations by approximately 12 and 20% respectively. This differential effect can be more clearly seen by comparing the percentage survival after 16 passes of a rotavator (Table III). Rotavation killed only 30% of Pratylenchus negelctus but 83 and 90% of L. elongatus and

TABLE I

Soil characteristics at 5 depths at the two experimental sites

Site	Location	Depth (cm)	Texture (% w/w)			pH	Organic matter (% w/w)	Bulk density
			Clay	Silt	Sand			
1	Scone	0-9	12	28	60	5.7	6	1.24
		10-19	16	24	60	5.7	6	1.3
		20-29	10	28	62	5.8	6	1.45
		30-39	10	22	68	6.0	3	1.39
		40-49	6	6	88	6.2	3	1.34
2	Invergowrie	0-9	9	18	73	5.7	12	1.31
		10-19	9	15	76	6.0	13	1.39
		20-29	8	16	76	5.9	9	1.40
		30-39	9	17	74	5.7	6	1.62
		40-49	15	21	64	5.6	5	1.68

TABLE II

The effect of ploughing to a depth of 20 cm on the survival of *Longidorus elongatus* and *Rotylenchus robustus*

Species	Depth (cm)	Initial population nemas/200 g soil	Percentage of original population surviving
Rotylenchus robustus	0-9	312	97
	10-19	276	98
	20-29	150	99
	30-39	35	102
	40-49	28	102
Longidorus elongatus	0-9	225	98
	10-19	258	98
	20-29	193	103
	30-39	172	98
	40-49	151	100

Trichodorus primitivus respectively. There was no significant differential effect on male, female or larval stages of *R. robustus* Rotavation also reduced the overall total nematode population which was mainly comprised of "beneficial" nemtodes i.e. mycophagous and bacteriophagous nematodes involved in the breakdown of organic material in the soil.

The effect of compaction on nemtode numbers can be observed in Table IV. Although proportionally more nematodes were killed in the top 7 cm of soil

TABLE III

Effect of rotary cultivation on the survival of a range of migratory plant-parasitic nematode species at two sites (0-20 cm soil depth)

Species	Initial population (nemas/200 g soil)	Percentage of original population surviving after 16 passes
Site 1		
Rotylenchus robustus (male)	17	29
R. robustus (female)	40	28
R. robustus (larvae)	94	32
R. robustus (total)	151	29
Trichodorus spp.	15	20
Overall total nematode numbers	1395	38
Site 2		
Longidorus elongatus	173	17
Paratylenchus microdores	151	41
Rotylenchus goodeyi	53	40
Pratylenchus neglectus	10	70
Tylenorhynchus dubius	3	0
Trichodorus primitivus	2	10
Monochids	34	20
Overall total nematode numbers	1738	43

a significant number below 15 cm were also killed. Increasing the number of tractor passes from 4 to 8 only slightly increased the numbers of nematodes killed. Compaction differentially affected the nematode species studied, proportionally more R. robustus being killed than T. primitivus and L. elongatus.

DISCUSSION

The results from the three experiments reported indicate that annual cultivation carried out by the average farmer would kill no more than 20-25% of the migratory plant-parasitic nematodes present. The reason for the differential effect of both rotavation and compaction on nematode numbers is not fully understood but probably reflects an interaction between soil factors e.g. soil stability (Brown and Swain, 1974) and characteristics associated with the different nematode species e.g. feeding site and body size (Jones et al. 1969). The decrease or restricted use of some nematicides and the increased concern over the use of chemicals has meant that other forms of nematode control are being investigated. The results from this work suggests that because relatively few nematodes were killed by cultivation this cannot be considered as an alternative to chemical control, which although expensive, can kill 95% of the nematodes present. However, both R. robustus and L. elongatus have very slow rates of multiplication in Scotland, populations increasing no more than two or three fold each year even with a good host e.g. grass (Boag, 1982; 1984; Boag and Geoghegan, 1984). Under these conditions cultivation may have a significant role in slowing down the build up of

TABLE IV

Effect of number of tractor passes and survival of a range of migratory plant-parasitic nematode species at two sites and three soil depths

Species	Depth (cm)	Initial population (nemas/200 g soil)	Percentage of original population surviving	
			4 tractor passes	8 tractor passes
Site 1				
Rotylenchus robustus	0-7	792	55.2	51.4
	8-14	486	58.6	59.5
	15-21	74	71.6	70.1
Trichodorus primitivus	0-7	117	75.6	69.8
	8-14	87	81.0	72.2
	15-21	54	82.8	70.7
Overall total nematode numbers	0-7	1579	77.0	69.2
	8-14	997	80.5	80.6
	15-21	382	82.7	76.9
Site 2				
Longidorus elongatus	0-7	162	84.9	73.9
	8-14	192	89.6	85.6
	15-21	98	94.0	87.5
Overall total nematode numbers	0-7	2031	55.8	43.9
	8-14	1793	88.5	85.6
	15-21	1181	89.1	82.7

populations to levels where economic damage may occur and help explain why migratory plant-parasitic nematode numbers are generally significantly lower in cultivated arable fields than those directly drilled or have perennial crops.

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NEW FIELD EXPERIMENTAL RESEARCH CONCERNING INDUCED SOIL COMPACTION IN ROMANIA

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ABSTRACT

Results are presented from four experimental fields located in various soil and climate conditions in Romania. Compaction was induced by 1 to 30 wheel-by-wheel tractor passes. Soil physical properties and crop yields were studied, as affected by:
- repeated compaction, 1, 2, and 3 years on the same plot;
- residual effect of compaction one or more years after cessation of the compaction treatments;
- self-loosening of the soil outside the vegetation period;
- loosening effects of ploughing and of an improving crop.

INTRODUCTION

Some 2/3 of the arable area in Romania is estimated to be affected by compaction (Canarache et al., 1984b). Results of field experiments carried out in 1979 - 1981, and dealing mainly with the influence of the number of passes on soil physical properties and crop yields have been published earlier (Canarache et al., 1984a). This paper presents results of a new series of experiments, carried out in the same plots in 1980-1985.

MATERIAL AND METHOD

The four experimental fields were located on a Chernozem soil (Valu lui Traian), a Reddish-Brown soil (Meara Demnească), and two Pseudogleyed Luvic Brown soils (Sînmartin-Oradea and Albota). In the upper soil horizons clay content varied between 25 and 30%, humus content between 2.2 and 3.1% and pH between 5.1 and 8.0. The yearly rainfall varied between 380 and 700 mm (being supplemented at Valu lui Traian by 160-240 mm of irrigation water), the yearly mean temperature between 9.8 and 11.2 C and yearly potential evapotranspiration (Thornthwaite) between 662 and 697 mm.

In cycle I, before research reported in this paper, the experimental layout consisted of nine parallel strips 60 m long and 7.2 m wide. The first, fifth and ninth strips were used as control (non compacted treatments). The other strips received 1, 3, 5, 10, 20 and 30 compaction treatments respectively. Compaction was done by wheel-by-wheel passes of a U-650 tractor, its weight being 3620 kg, and the inflation pressure in the rear wheels 120 kPa. Soil moisture content at compaction time was slightly below field capacity. The soil in the experimental field was ploughed (22-25 cm deep) every autumn, and it was recompacted before sowing, the same autumn or next spring according to the crop following.

In cycle II (only at the Moara Downească and Albota sites), the same experimental layout and the same way of inducing compaction were used, but each of the three years a new experimental field, close to the previous one, was started. As a result, the third year of cycle II three neighbouring annual sequences compaction - ploughing repeated one, two and three times, and each including the non compacted control and the six compaction treatments, were present.

During the autumn of the last year of cycles I/II a new experimental layout was established, using another series of parallel strips, crossing at a right angle the previous ones.

In cycle III, two tillage treatments were used on these new strips: disking (8-10 cm deep), and ploughing (22-25 cm deep).

At two sites (Valu lui Traian and Sinmartin-Oradea), the new experiment also included in the first year following cycles I/II two crops, differing in type and development of the root system and, as a consequence, in their ability to improve the soil physical properties: maize and Lolium multiflorum. This was cycle IVa. Next years (cycle IVb), to enable comparison, a single crop raised.

Soil samples were taken in the last year of cycle I/II and in the second year of cycle III/IV, and bulk density, saturated hydraulic conductivity, soil moisture characteristic, and resistance to penetration were determined using standard methods in this country (Obrejanu et al., 1964), but only data on bulk density will be reported here. Crop yields were recorded every year. Soil sampling and yields measurements were done on four subplots in each strip. As most of the interactions were not significant, only results related to averages for main factors will be discussed in this paper.

RESULTS AND DISCUSSION

<u>Effect of repeated compaction</u>. Figure 1A shows an increase in compaction (bulk density) from the first to the second and to the third year of repeated compaction. Taking the 10 passes treatment as an example, bulk density was greater than in the non compacted soil by 7% with one compaction, by 14% with two compactions, and by 17% with three compactions. This increase was noticed in the upper soil layer following one or two repeated compactions, but in the subsoil too after three compactions (Figure 1B). It is a remarkable finding, taking into account that soils in the experimental fields have been cropped for many years under heavy mechanization, being already compacted before starting the experiment.

The effect of repeated compaction on crop yields is presented in Figure 1C. There was a normal decrease in yields as the number of passes increased. There also was a reduced, but statistically significant, increase in the general level of yields when repeating compaction two or three years. This is not easy to explain. Soil aggregates, of low porosity but relatively high stability, resulting from compaction, might under certain conditions have a positive effect on the air and water regime, but further research is certainly necessary.

<u>Residual effect of compaction</u>. Figure 2 shows the relationships between number of passes in the preceding cycle and bulk density or crop yields for the ploughed treatment and the persistence of significant changes is to be noticed. Taking as an example the previous 10 passes compaction treatment, there was in the first year after cessation of the compaction treatments, a 2% increase in bulk density and a 14% decrease in yield. Smaller differences were still present in the fourth year of this post-compaction experimental cycle.

These results again show the complexity of the compaction problem. The negative effect of compaction lasted at least several years, and this in part is an opposite conclusion as compared to the one in the preceding paragraph.

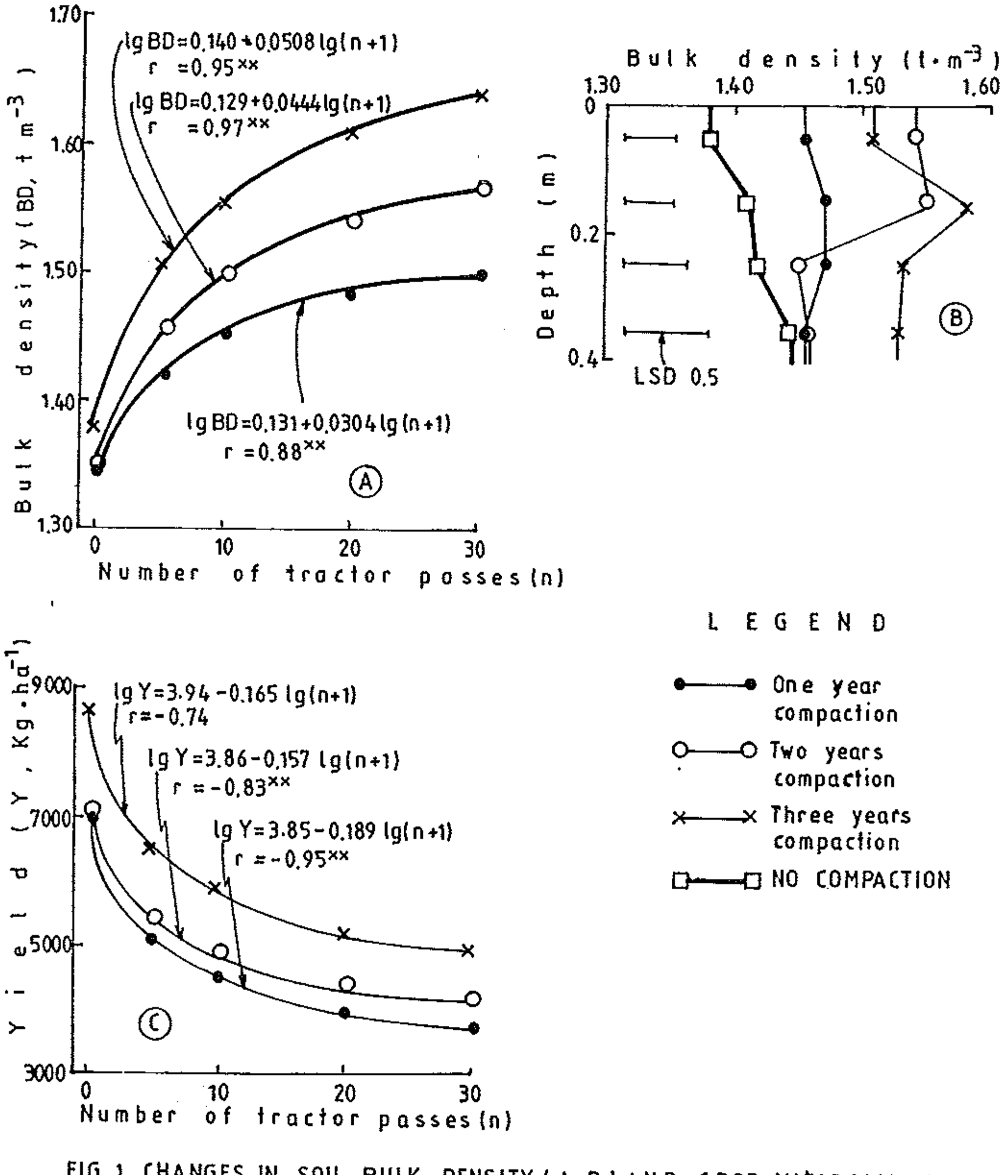

FIG 1 CHANGES IN SOIL BULK DENSITY (A,B) AND CROP YIELDS(C) AS AFFECTED BY REPEATED COMPACTION TREATMENTS (CYCLE II)(MAIZE, MOARA DOMNEASCA, 1980 - 1982; ALBOTA, 1981 - 1983)

Self-loosening. The curves in Figure 2 referring to the disking treatment show an important decrease of residual compaction effects as compared to the previous experimental cycle. In the previous 10 passes compaction treatment there only was an increase in bulk density of 3%, and a decrease in yield of 16%, as compared to the control, although there have been no mechanical loosening of the earlier compacted soil. This self-loosening process was effective down to ca. 20 cm depth (Figure 3A). Such changes in soil properties and in crop yields were of course the result of the freezing - thawing and wetting - drying cycles.

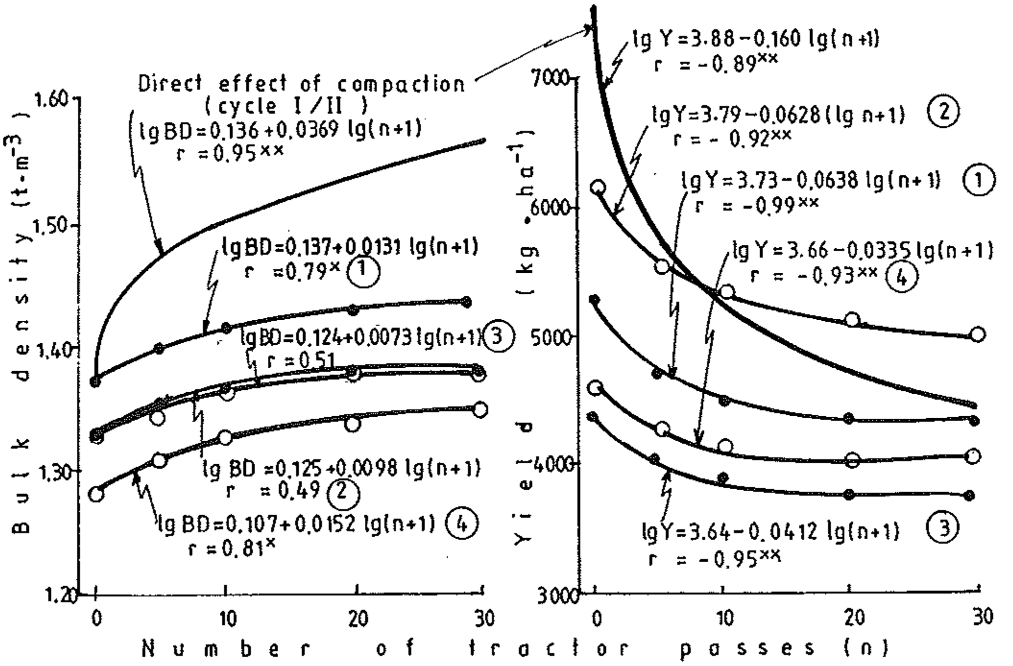

FIG 2 CHANGES IN SOIL BULK DENSITY(A) AND CROP YIELDS(B) AS AFFECTED BY TILLAGE (CYCLE III) AND CROP SEQUENCE (CYCLE IV) AFTER CESSATION OF COMPACTION 1 DISK; 2 PLOUGH (1 AND 2: VALU LUI TRAIAN, 1982 MAIZE AND LOLIUM, 1983 BEANS; MOARA DOMNEASCA, 1983 MAIZE; SINMARTIN-ORADEA, 1982 MAIZE AND LOLIUM, 1983 MAIZE; ALBOTA, 1984 AND 1985 MAIZE); 3 PRECEDING CROP MAIZE; 4 PRECEDING CROP LOLIUM (3 AND 4; VALU LUI TRAIAN, 1983, BEANS; SINMARTIN-ORADEA, 1983, MAIZE, 1984 WINTER WHEAT, 1985 MAIZE)

This is an encouraging element in forecasting the future development of soil physical status. It shows that, under this country's climate, there is a significant trend for natural alleviation of compaction.

Loosening effect of tillage. We may also compare in Figure 2 the curves referring to the ploughing treatment in cycle III to that from cycle I/II. This comparison enables a quantification of mechanical loosening effects. It shows, for the previous 10 passes compaction treatment, a decrease of 6% in bulk density. In Figure 3A the positive effect on bulk density of ploughing may be noticed mainly in the 10-30 cm layer.

Comparing the ploughing treatment to the disking one, there was a 3% percent decrease in bulk density and an 8% increase in yields, but these figures are not very convincing as they include not only the effect of alleviating compaction, but also the usual better effect of ploughing as compared to disking for row-crops in this country.

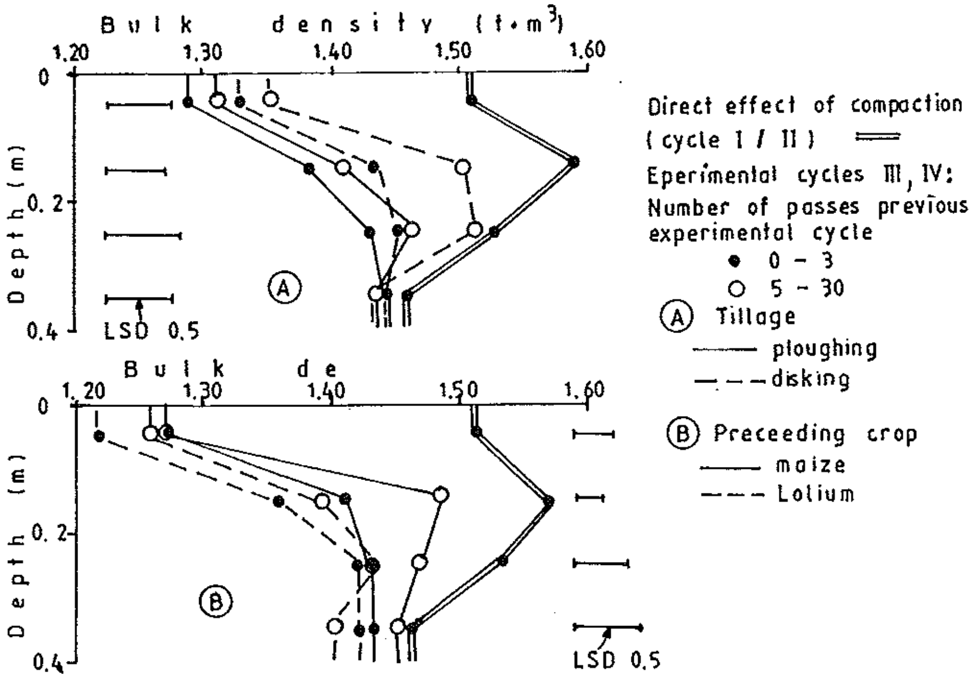

Fig 3 DEPTH VARIATION OF SOIL BULK DENSITY AFTER CESSATION OF COMPACTION AS AFFECTED BY (A): TILLAGE (CYCLE III)(VALU LUI TRAIAN, 1983; MOARA DOMNEASCA, 1983; SINMARTIN-ORADEA, 1983; ALBOTA 1984, 1985); (B) CROP SEQUENCE (CYCLE IV) (VALU LUI TRAIAN 1983; SINMARTIN - ORADEA, 1983)

Loosening effect of an improving crop. The other two curves in Figure 2 enable to compare results in the second and following years of cycle IV for plots where in the first year of this cycle different crops have been raised. For the previous 10 passes compaction treatment, bulk density under maize following Lolium was 4% lower than under maize following maize. There also was a yield increase of 16% which might be attributed both to compaction alleviation and to other positive effects of Lolium as a preceding crop. As shown in Figure 3B, the different in bulk density between the two crop rotation treatments is to be noticed at the 10-30 cm depth.

Results in this paragraph support using, as a method to improve the soil physical status and to loosen severely compacted soils, crop rotations including an improving crop.

CONCLUSIONS

1. The increase in bulk density due to traffic compaction became more intense as the number of annual compaction treatments increased. This increase was still noticed, even with ploughing as a loosening treatment, at least two years after cessation of the compaction treatments. Nevertheless, it diminished in intensity, even without ploughing, due to self-loosening processes.

2. The decrease in crop yields due to compaction had a more complex character. It had a residual character, even with ploughing, and diminished due to self-loosening even without ploughing. On the other hand, under the conditions of this experiment, it diminished in intensity with increased number of annual compaction treatments.

3. Including an improving crop (Lolium multiflorum in this case) in the crop rotation had obvious positive effects both on soil bulk density, and on crop yields in the following years.

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ZONE PRODUCTION RESEARCH WITH WIDE TRACTIVE RESEARCH VEHICLE

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ABSTRACT

Zone production systems for field crops in arid areas with sandy soil using controlled traffic are being studied for alternatives to existing random traffic production systems. The current research is being conducted using a Wide Tractive Research Vehicle (10-meter spanner) permitting studies of location and force of compacting wheels as well as creation of special soil zones. Demonstrated advantages for zone systems include increased low impedance soil for root exploration, increased water infiltration and water efficiency, improved rooting in the surface 60 cm and potential for elimination of all but surface tillage. Tillage has been shown to be detrimental to water conductivity in non trafficked soil.

INTRODUCTION

Zone systems with controlled traffic have been proposed as an improved cultural practice for field crops for many years. Carter et al. (1971) reported research conducted between 1962 and 1968 studying the effect of separating the field into three zones "(a) a root development volume, (b) a water infiltration area and (c) a traffic support area". Later studies had similar conclusions (Carter, 1985; Williford, 1980; Dumas, 1973; Taylor, 1983); the effects of controlled traffic upon soil properties are predictable but the crop response is variable. Traction efficiency, root exploration and water (irrigation or rain harvest) efficiency should be greatly improved and total energy for soil management should be significantly reduced. Yet over the years that information from research and extension studies have been reported, few farmers have adopted or adapted a controlled traffic or zone system. Farmers apparently have concerns about the overall economics of a controlled traffic system or zone systems in general. The research reported here was prompted by the need for additional information. The USDA, ARS, research program at Shafter California has long term goals for development of the zone production concept. For the near term, however, sufficient information for farmer evaluation should be developed quickly.

The first evaluations of controlled traffic and zone systems were accomplished with modified commercial equipment. The wide tractive research vehicle (WTRV) was obtained in 1982 to eliminate what had been considered the greatest barrier to understanding the agronomic and soil response: practical limitation of wheel spacing of 2 to 2.5 meters. The WTRV has a span of 10 meters with sufficient weight and power for all tillage, management and harvest operations for field crops. The background for the research reported here include multi-discipline evaluations of zone systems on cotton and alfalfa beginning in 1983, as well as independent studies of the soil response to traffic and tillage. This report which accompanies a poster presentation is a broad review of certain aspects of the research. The work was partially supported during 1985 through 1987 by the United States-Israel Binational Agricultural Research and Development Fund (BARD).

METHODS

The research was conducted at the USDA Cotton Research Station, Shafter, California (USA). The soil is a coarse-loamy, mixed, nonacid thermic Xeric Torriothent. Rainfall is 160 mm per year with little rain from May to September.

Plots were 8 m wide and of varying lengths, between tests, arranged in randomized block designs. The plots were separated by two-meter wide buffer areas each with a centered one-meter wide, raised, compacted, soil zone providing stable paths for the WTRV on 10-meter centers. Each test included, among others, a conventional treatment using tillage and equipment with traffic patterns and axle loads based upon a survey of farms within 50 km (farmer's practice) and a "zone" treatment with no traffic and with no primary tillage between crops. All operations, including sampling, for the zone treatments were accomplished with special attachments to the WTRV to eliminate any traffic related forces. The amount and timing of furrow or basin irrigations were based upon plant and soil water stress measurements.

Standard procedures of ASA and ASAE were used for soil characterization of bulk density, water movement and penetration resistance.

RESULTS AND DISCUSSION

Within all trials the zone system treatments universally exhibited markedly lower soil impedance (cone index). Soil impedance was characterized by obtaining cone index on a 10-cm (horizontal) by 5-cm (depth) grid pattern. The distribution of the cone index measurements within a 4 meter wide by 1 meter depth soil profile approximate normal curves for the two systems. Both the impedance mean and standard deviation for the zone system were approximately 60% of those for the conventional system. The increase in soil impedance was much greater in all studies as a result of concentrated traffic after furrows were established compared to the soil-preparation random traffic. Therefore the mean differences in cone index between treatments are inadequate for characterization of the effect of traffic and the spatial and statistical distribution of cone index must also be considered. Using the data obtained in September, 1988, from a study initiated in December, 1985, 80% of the soil within the zone system had a cone index between .2 and 1.4 MPa compared to .4 and 2.4 for the conventional system. Similarly, at the high impedance end of the distribution, 20% of the zone system soil was between 1.2 and 1.9 compared with 2.0 to greater than 3.2 MPa for the conventional system. The pre-furrowing random traffic increased the soil impedance .4 to .6 MPa at depths of 30 to 40 cm. However the impedance was increased by 1.2 to 1.8 MPa by multiple passes of planter, cultivator, pest management, and harvester traffic in a zone 40 cm wide by 50 cm in depth under the trafficked furrows compared to the non-trafficked furrows.

The changes in soil bulk density with traffic were no different than would be expected from accepted theory. The increase could be reversed with tillage in these trials. In a three year study where no random traffic was applied to any treatments the soil bulk density under the plant row was not increased by furrow traffic on 1 meter centers when the soil was deep tilled (subsoiled to a depth of 55 cm on 50 cm centers) between crops. However when there was no inter-year deep tillage there was a trend with time for increasing bulk density levels under the plant row over years at depths greater than 35 cm. Bulk densities exceeding 1.8 Mg/m^3 were measured under the trafficked furrows in the second year where no deep tillage was applied between crops. With annual tillage the maximum bulk density under the trafficked furrow increased to 1.68. In treatments with no furrow traffic as well as no random traffic, the bulk density stabilized at 1.55 for all combinations of tillage or no tillage and furrows or beds. Water infiltration with no traffic was significantly reduced by inter-year deep tillage (4.1 to 3.2 cm/hr). Since the infiltration difference was not associated with a difference in soil bulk density or cone index we have proposed that tillage disrupted existing macro pore water passages thus reducing the conductivity.

The response of water infiltration rate to removal of all traffic is quite different for cotton (an annual crop planted on raised beds) than for alfalfa (an multi-year crop planted in basins). The water infiltration rate during the first post planting irrigation for cotton each year was inversely related to the soil mechanical impedance and to the upper profile soil bulk density. The infiltration rate decreased with time for both zone and conventional systems approaching the same rate after 4 irrigations. In the cotton system test initiated in 1985 the initial water infiltration rates were 21 and 12 mm/hr for zone and conventional decreasing to 6 mm/hr after the 6th irrigation for both systems. The initial difference is of the same magnitude as the difference in the mean soil impedance (approximately 60%). The difference in surface (15 cm) soil bulk density was 10% (1.68 for zone and 1.83 for conventional). Traffic had a similar effect on initial water infiltration in a multi-year alfalfa study. During the first three irrigations the infiltration rates decreased as with cotton. However after this initial period, the infiltration rates for both systems increased during a three year period with the difference remaining nearly constant. For example, traffic reduced the hydraulic conductivity at the 0.02 to 0.11 meter depth by 60% compared to no traffic corresponding to soil bulk densities of 1.62 and 1.83 for zone and conventional. Over a three year period the water infiltration rate increased 3-fold and 2-fold for the zone and conventional systems respectively. Measurement of macro pores in this study indicated that water continued to flow through old root channels even with high bulk densities, thus without tillage and with litter from previous harvests on the surface, water infiltration rates increase for alfalfa both within and over years (Meek, 1988).

Presuming that root penetration was not totally impeded by a barrier (as was the case for these studies) the total length of roots was the same for zone and conventional systems at depths below 60 cm (the depth of tillage) but varied with time and treatment in the surface 60 cm. For example in a three year alfalfa study the total length of roots under traffic paths was reduced to 92% between the surface and 30 cm after the first season decreasing to 43% after the third year compared to non trafficked areas. The corresponding data for the soil between 30 and 60 cm in depth was 90% and 53%. The cone index for the zone system soil increased linearly with depth from .2 to .9 MPa. In the conventional system the cone index was fairly constant at 2.0 MPa to a depth of .35 cm then decreased to 1.2 MPa. Below 60 cm the cone index of both treatments was approximately 1.0 MPa. Thus root proliferation may be predicted by a knowledge of the soil penetration resistance profile (Taylor, 1971). The implications of these differences on root and shoot physiology and root-soil-water interactions need investigation (Rechel, 1988).

CONCLUSIONS

1. Zone systems based upon controlled traffic offer an opportunity to eliminate primary tillage and thus reduce the cost of production for field crops grown in arid areas on sandy soils. Secondary or cultivation tillage may be required to prevent surface soil particle sealing and for pest management.

2. The volume of soil available for root exploration can be substantially increased by eliminating all traffic. Practical farmer systems using controlled traffic would decrease the soil available for root exploration related to the proportion of surface soil compacted.

3. Removing traffic compaction has the potential to double the water infiltration rate thus improving irrigation efficiency and increasing rain capture.

4. Tillage reduced water infiltration rates in non trafficked treatments possibly due to disruption of macro-pore water channels. This effect was not observed in trafficked soil.

5. Without yield increases the economic advantage of zone systems is related to reduction in cost of tillage, increases in water management efficiency, increases in rooting efficiency and factors related to management. Other postulated advantages related to yield, soil micro-organism populations and dynamics, root physiology, pest management, etc. have not been studied sufficiently to reach meaningful conclusions.

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REDUCTION OF TRAFFIC-INDUCED SOIL COMPACTION BY USING LOW GROUND PRESSURE VEHICLES, CONSERVATION TILLAGE AND ZERO TRAFFIC SYSTEMS

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ABSTRACT

An EEC collaborative programme of research investigating methods to avoid soil physical degradation from field traffic in the Netherlands, Germany, Scotland and England is described. Results from a four year replicated trial which studied the effects on soil and wheat responses to field vehicle traffic in South East England are presented. During shallow cultivation, energy input on unwheeled soil was c.50% less than the 200 MJ/ha required following conventional traffic, whereas energy was increased slightly with low pressure traffic. Cone resistance and soil dry bulk density below 100 mm generally increased with wheeling pressure, but the greatest differences were between wheeled and unwheeled soil. The yield of wheat in the first two years was reduced on untrafficked soil by manganese deficiency, but subsequently, where a prophylactic treatment of manganese sulphate was made, no differences in yield were recorded. Recently the practical and economic potential of a zero traffic system was explored by constructing a 12 m track gantry.

INTRODUCTION

In Northern Europe the trend towards monocultural cropping, reduced cultivation inputs and an increase in the weight of farm vehicles has resulted in many soils becoming over-compacted. These are characterised by impeded plant growth, low water infiltration rates and accelerated erosion (Soane et al, 1982). There has also been evidence in these soils of increased cultivation energy inputs for a given depth of operation (Chancellor, 1976) and this has required even larger and heavier tractors to maintain output.

These problems have mostly been investigated by countries individually, but the opportunity for a collaborative project was provided by the Land and Water Use and Management programme of the European Commission. In 1985 it provided a proportion of the funds necessary for a four year joint research project between Germany, the Netherlands and UK to investigate methods to avoid soil physical degradation resulting from inappropriate traffic induced compaction. In the Netherlands work on high, low and zero pressure traffic was introduced, but has concentrated on the high (1.6 to 2.5 bar) and low ground pressure (LGP) (0.4 to 0.8 bar) systems in a rotation of sugar beet, onions, potatoes and winter wheat. In Germany similar systems growing sugar beet, wheat and barley have been introduced using both conventional and conservation tillage techniques.

Work in the UK has been divided between Scotland and England. In the cooler, wetter climate of Scotland, high, (conventional) low and zero traffic systems were introduced on a ryegrass sward used for intensive silage production and in 1987 this experiment was augmented by a trial growing potatoes using conventional and zero traffic. Experiments in England have concentrated on similar traffic regimes growing winter wheat, but more recently work has concentrated on the development of a 12 m track gantry for arable cropping. The objective of this work was to produce a prototype machine capable of carrying out all operations on a cereals farm and to consider the practical problems associated with such a machine, to assess the energy inputs required, to study the economics of the system and to measure soil and crop responses to zero traffic. This paper deals with the replicated trial and gantry development undertaken in England while results of work on the project in Scotland, Germany and the Netherlands is reported elsewhere at ISTRO 88 by the co-authors of this paper.

METHODS

The three levels of tyre/soil contact pressure applied to the trial area in South East England for 4 years were: (i) High (H, up to 2.5 bar), (ii) LGP (L, up to 0.55 bar) and (iii) Zero (Z, no wheelings on cropped area). The H treatment was applied with conventional tractors and equipment and the LGP with similar machines having additional traction tyre volume. Z regimes were achieved in narrow beds by using 2.4 m track tractors and machines on permanent uncropped tramlines. Wheat was established, after burning the straw and stubble, using shallow tine cultivation and drilling (SC) and direct drilling (DD). Wheelings were only applied during normal cultural operations. Measurements on the 35 m long by 24 m wide replicated plots included soil dry bulk density, cone penetration resistance, cultivation draught and energy requirements, depth of sowing, plant establishment and crop yield. The generally level site at an elevation of 59 m on an Evesham series soil had a mean clay content of 60%, pH level of 8.0 and organic matter content of 5% by weight. Prior to 1980 cropping was predominantly grass, but spring barley was grown in 1981 and winter wheat in 1982. The site was mole ploughed and deep loosened in autumn 1981 prior to applicatin of the treatments in 1982. Mean annual rainfall was 550 mm distributed evenly throughout the year.

Performance trials with the gantry were on two soils which had been deep loosened in autumn 1986. Permanent beds and soil-based wheelways were created in spring 1987 and both sites were sown with spring barley using the gantry. Subsequently, because a gantry based harvester had not been completed, the crops were sprayed off and chopped in situ. The economics of gantry systems were studied using an Arable Farm Model (Audsley 1981) which maximised an objective function (profit) subject to a series of constraints.

RESULTS

Mean soil dry bulk density measured in the 0 to 400 mm profile of the SC plots with a twin probe high resolution nucleonic density meter (Henshall and Campbell, 1983) in March 1986, was 13% greater after conventional (H) wheelings compared with zero traffic. Similar but smaller differences were recorded on the DD plots. Values for LGP traffic tended to be intermediate, except in the top 100 mm, where both these and earlier results (Chamen et al, 1985 and 1987) indicated an increase in density compared with the H treatments (Table I). Cone resistance measured with

Table I Mean soil dry bulk density with depth, March 1986, kg/m^3

Traffic	H		L		Z	
Cultivation	DD	SC	DD	SC	DD	SC
Depth, mm						
50	830	867	912	833	753	735
100	1043	1091	1013	997	968	981
200	1116	1153	1061	1105	1055	1034
300	1169	1244	1119	1102	1112	1019
400	1259	1274	1220	1249	1202	1194

SE_D vertical comparisons ± 37, horizontal (same cult.) ± 37, interactions ± 39

a Bush recording penetrometer showed similar trends, revealing an average 26% increase in resistance with depth on the trafficked compared with the untrafficked soil (Fig. 1).

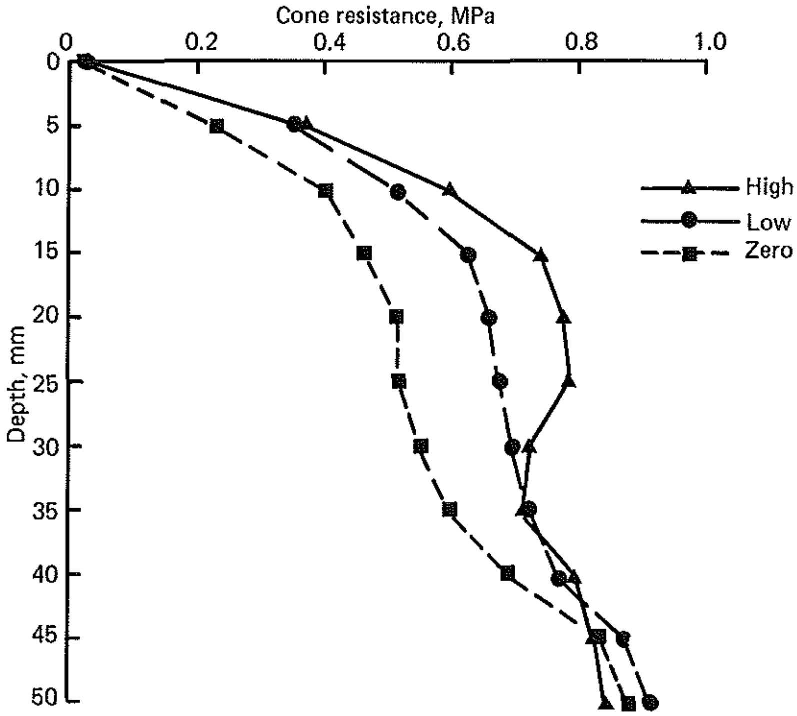

Fig. 1. Cone Resistance with Depth Meaned for each Traffic Treatment.

The draught requirement of the shallow tine cultivator reflected these measurements and was increased by 60% on the High and by 83% on the LGP plots compared with on untrafficked soil. In practice, the Z plots were also more easily worked in very dry conditions and often required only one rather than three cultivations to create a seedbed. The construction of the implement could also be lighter, but it needed a closer tine spacing (120 mm compared with 285 mm).

The total energy requirements for each of the systems are shown in Table II.

Table II Tractor energy (MJ/ha) for cultivations and drilling in autumn 1985 calculated from fuel use. (Mean depth of seed placement, mm, on DD plots)

	H	L	Z
SC	178	182	51
DD	48 (50)	40 (39)	36 (56)

Differences in plant population were only significant in the first year of the trial (within the range 328 to 375 plants/m^2) and mean depth of sowing varied by less than 20 mm between treatments in all years.

The overall effect of cultivation treatment (DD or SC) on crop yield was not significant in any year, but in 1985, the ZSC treatment returned a significantly lower yield than that following the ZDD treatment. This effect could not be explained. The negative yield response from the zero traffic systems in 1983 and 1984 (Table III) was to some extent the result of manganese deficiency in the crop, brought about by loose seedbed conditions in combination with the high pH and soil organic matter content. A prophylactic treatment of manganese sulphate was applied in subsequent years and a significant yield loss was then only recorded on the Normal treatment compared with the LGP.

Results of trials with the 74 kW gantry showed that on unwheeled cereal stubble both an 11.5 m wide spring tine cultivator and a 1.92 m wide (6 furrow) shallow plough could be pulled at up to 8 km/h. The plough working at 130 mm depth was used in three lateral positions on the gantry to complete an 11.5 m wide bed. Drilling of spring barley was accomplished with a 4 m mounted pneumatic drill used in just two positions.

Table III Mean crop yields and SE_D of the means for each traffic treatment

	H	L	Z		
1983	8.88	8.71	7.39	(N-Z)=1.49 ± 0.30***	(L-Z)=1.32 ± 0.30***
1984	8.02	8.48	7.67	(L-Z)=0.81 ± 0.22**	
1985	5.52	5.44	5.29		
1986	6.54	7.22	6.87	(L-N)=0.68 ± 0.25*	

Significant at 0.1% level***, 1% level**, 5% level*

In view of a need recognised from the replicated field trials to provide some firming of seedbeds, a mounted roll was designed for the gantry. This consisted of four separate 2.9 m wide units each weighing c.330 kg. In work, additional weight was transferred to the rolls from the gantry. Trials with this unit have been limited to date. To retain the unwheeled beds from one season to the next, an experimental harvesting system based on a stripping header, (Klinner et al, 1987) is being developed for the gantry and should be available for autumn 1988.

Investigation of the permanent wheelways showed that these needed soil bringing into them periodically, but not to the extent of eliminating a side wall, which was necessary for lateral support of the wheels. Drainage of the wheelways was also vital and a slanting tine arrangement designed by Spoor et al (1988) to do these two jobs is now undergoing trials.

Results of economic studies on a 200 ha cereals farm showed that on a sandy clay loam soil, despite the high cost of a gantry (£50,000), the lower inputs required for cultivation enabled farm profit to be improved slightly compared with a conventional system. This result included use of a transport gantry (£35,000), a gantry mounted harvester (£60,000) and no yield benefit from zero traffic. On a clay soil, the profitability of the gantry system was further increased compared with the conventional system.

DISCUSSION

The increase in density and cone resistance of the top soil and the corresponding increase in implement draught with the LGP system may be explained by the larger area wheeled during each operation. In just two passes with an implement 4 m wide, the LGP tractor covered 100% of the ground with tyres; the equivalent figure for the conventional system was 43%. The dramatic reduction in energy demand on the ZSC plots was the combined effect of a lower draught requirement for a particular implement and the necessity for only one or two passes. This was possible because the soil tilth created 12 months earlier had not been destroyed by repeated wheelings. For the same reason direct drilling on the ZDD plots could mostly have been without a specialised drill.

It is unlikely that the manganese deficiency on the zero traffic plots would occur widely and its effect may be overcome by applying manganese sulphate to the crop, or possibly by firming the soil slightly in early spring. The success of ploughing with the gantry, although as yet only indicated by limited trials, is encouraging and means that operations ranging from direct drilling to conventional ploughing techniques can be contemplated. The economics study provided a useful indication of the considerable cost savings brought about by the reduced cultivation inputs of a gantry system and also showed how much could be spent for example on developing appropriate harvesting equipment.

CONCLUSIONS

1. Compaction of a clay soil, as measured by soil dry bulk density and cone resistance, increases with wheeling pressure in the 100 to 500 mm depth profile. In the 0 to 100 mm profile this relationship is less clear and account may have to be taken of the area wheeled per pass in

addition to the wheeling pressure.

2. Differences in the draught and energy requirements of a shallow tine (100 mm) cultivator reflect differences in the density and cone resistance of a particular soil.

3. If traffic is eliminated from the cropped area of a clay soil, the energy requirements for crop establishment can be reduced by up to 70%.

4. The loose seedbed conditions produced by a zero traffic system may adversely affect the yield of wheat by triggering a manganese deficiency in the crop. An application of manganese sulphate appears to overcome this problem.

5. A gantry system providing unwheeled wide beds would appear to be both practical and economically attractive for most cereal farm operations. A method of harvesting with the gantry should be developed, and a means of firming seedbeds may need to be introduced on certain soils.

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HARDPAN DEVELOPMENT IN LOAMY SAND AND ITS EFFECTS UPON SOIL CONDITIONS AND CROP GROWTH

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ABSTRACT

During 1984 and 1985, the effects of seven compaction treatments ranging from zero traffic to ten tractor passes across the full width of experimental plots on the structure of a previously ripped loamy sand profile and on subsequent wheat yields have been studied. Increased traffic resulted in increased soil strength and compaction, with cone resistance at 19-cm depth ranging from 2.2 to 4.1-MPa in the winter. Under conditions of high moisture stress when the reformed hardpan was most effective in reducing root penetration and hence the availability of both water and nutrients for later growth, wheat yields were reduced (up to 34%) and were generally less than for the original unripped soil.

INTRODUCTION

In recent years there has been a trend towards the use of heavier tractors, tillage and harvesting equipment on Australian farms. Söhne (1953) showed that increased weight increases the severity and depth in the soil profile to which compaction occurs. Many recent experiments in both Europe (Canarache et al., 1984; Blackwell et al., 1986; Campbell et al., 1986; Soane et al., 1986) and North America (Fausey and Dylla, 1984; Voorhees et al., 1985; Chaplin et al., 1986) have examined the effects of traffic on soil compaction in those regions.

Light soils in Western Australia tend to develop a hardpan soon after being taken into cultivation. These soils show a marked reduction in root growth in the compacted zone (Hamblin and Tennant, 1979) and have in many cases been shown to respond to deep tillage with substantial increases in yield (Jarvis et al., 1985).

The present study examines the effects of deep ripping followed by wheel traffic on soil physical properties and crop yield, associated with subsequent hardpan redevelopment on a loamy sand soil.

MATERIALS AND METHODS

Site, climatic and soil conditions

The experiment was conducted at the Wongan Hills Research Station of the Western Australian Department of Agriculture, where the average annual rainfall is 345-mm and the average annual Class A pan evaporation is 2521-mm (Luke et al., 1987).

The soil has been classified as a Typic Xeropsamment (Soil Survey Staff, 1975) and was a well drained, deep, loamy sand, which is common in much of the north and central Western Australian wheatbelt. The soil site was last cropped in 1980 and had been under pasture between 1981 and 1983. A distinct hardpan had developed at 15 to 20-cm depth. Some physical properties of the soil are presented in Table I.

TABLE I

Soil physical properties

Depth (cm)	Particle size distribution (%, w/w)			Water content at field capacity (%, w/w)	pH (water)	Organic matter content (%, w/w)
	2000–60	60–2	<2 μm			
0–10	82	14	4	15	6.1	0.9
10–20	76	16	8	12	5.6	0.5
20–30	72	17	11	14	5.7	0.2

Treatments and measurements

In November 1983 experimental plots measuring 40 x 2.5-m with a 2.5-m buffer between each plot were arranged in three replicate blocks. For each replicate seven plots were deep ripped (R) to 30-cm using an Agrowplow, achieving rips on 16-cm spacing, and two plots were retained as controls (UR) in which the original hardpan remained intact. The traffic treatments chosen were zero (0P), one (1P), three (3P), five (5P), ten (10P) passes and five passes on 1/2 wheel overlap (5P1/2) of an unladen tractor applied uniformly across the full plot width. A 5.2-t tractor (Table II) was used

TABLE II

Tractor tyre data

	Tyre size	Inflation pressure (kPa)
Front	900–16	193
Rear	23.1-26	110

to apply the five recompaction treatments to the ripped plots in early May 1984. Zero traffic was applied to the remaining two ripped and two unripped plots per replicate. Before sowing a crop of winter wheat using a 12-run-combine, all plots except one each of the R/0P and UR/0P plots were scarified (SC) with a 3-m-scarifier and harrows to 10-cm depth. The trial was cropped again in 1985 with the SC treatment applied as described above after the stubble had been burned.

Penetration resistances were measured to 0.47-m depth using a Bush recording penetrometer (Anderson et al., 1980). Transects of 10 penetrometer probings were taken in randomly chosen areas of each plot at 0.2-m lateral spacing. At the same time the gravimetric soil water content was measured using ring samples from a location near the penetrometer probings to 0.35-m depth at 0.05-m depth intervals per plot. Similarly, for determination of bulk density and saturated hydraulic conductivity, K_{sat} (Hartge, 1971), soil cores with a diameter of 73-mm and a height of 100-mm were sampled from two positions per plot (UR/0P, R/0P and 3P treatments only) to 0.40-m depth at 0.05-m vertical intervals. Soil strength and water content measurements were repeated throughout the growing season at monthly intervals. The soil cores for bulk density and K_{sat} were taken immediately after application of the recompaction treatments.

A modified combine harvester with a 1.78-m cut width was used to harvest 10 rows of wheat from the middle of each plot for the grain yield determinations.

RESULTS AND DISCUSSION

Soil conditions

The deep ripping operation disrupted the hardpan at 15 to 20-cm depth. Subsequent wheel traffic recompacted the loosened soil according to the number of wheel passes, with penetration resistance at 19-cm depth for the R/0P and 10P treatments being 12% and 67% respectively of the UR/0P treatment (Fig. 1a). There were no significant differences in penetration resistance between the 10P and 5P1/2 treatments.

TABLE III

Hydraulic conductivity on 17 May 1984

Depth (cm)	Saturated hydraulic conductivity, K_{sat} (m/d)			
	UR/0P	R/0P	3P	Std. error
0–20	7.8[a]	34.4	7.9[a]	2.00
20–40	16.6[a]	23.6	13.8[a]	1.98

[a] Different from R/0P at 1% level.

The average soil water content on 17 May 1984 ranged from 9% (w/w) at 5-cm depth to 8% (w/w) at 35-cm depth with differences between treatments being very small and not significant. K_{sat} was significantly higher after ripping but after recompaction with three tractor passes, K_{sat} showed no significant differences when compared with the undisturbed hardpan (Table III).

Although remains of the original hardpan were still evident, deep ripping reduced soil bulk density to a depth of 30-cm (Fig. 1c). The 3P treatment recompacted the soil bulk densities to similar values to those found for the undisturbed UR/0P treatment. However, recompaction to the same bulk densities does not necessarily produce as high penetration resistances as were found in the original hardpan. For example even though bulk densities for 3P and UR/0P were similar, penetration resistance values were lower for the 3P treatment (Fig. 1d). These results suggest that chemical bonding contributes significantly to the hardpan strength and that the passage of time enhances the cohesive bonds between particles.

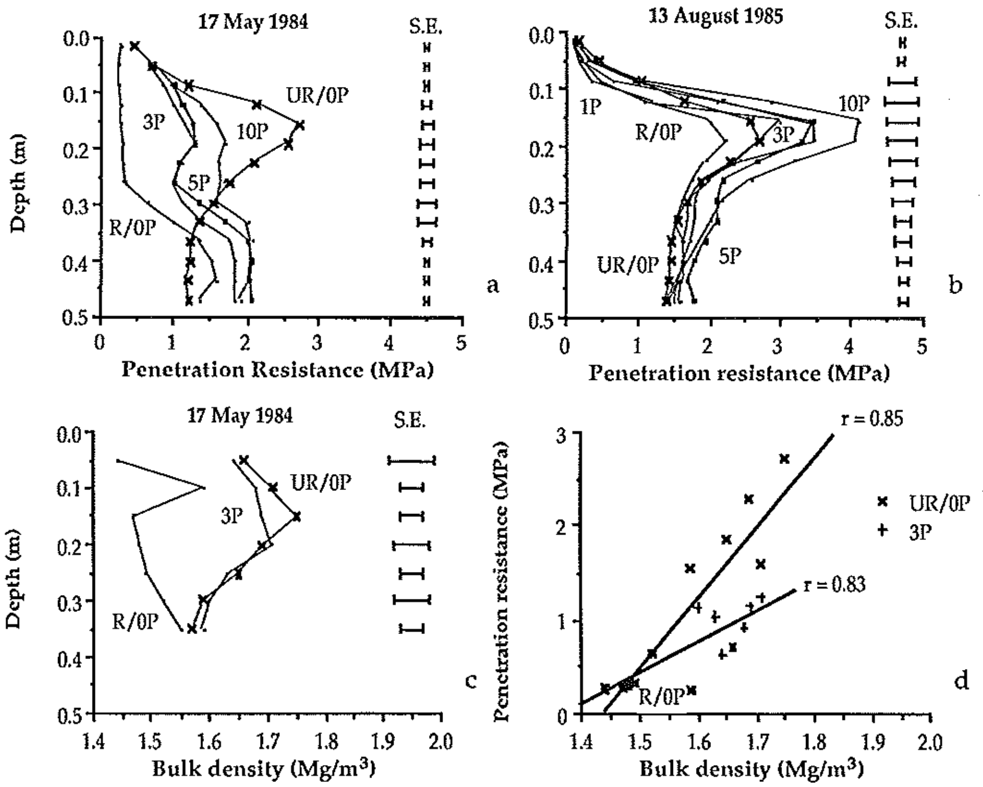

Fig. 1. Effects of deep ripping and subsequent recompaction on (a) and (b) penetration resistance at different dates and (c) bulk density. (d) Correlations between bulk density and penetration resistance on 17 May 1984 for zero traffic (0P) data (unripped and ripped), and for combined ripped (0P) and recompaction (3P) data.

Typical penetration resistances after crop emergence are shown in Figure 1b. The hardpan reformed at 15 to 20-cm depth with penetration resistance at 19-cm depth for the R/0P and 10P treatments being 83% and 150% respectively of that of the UR/0P treatment.

The average soil water content on 13 August 1985 increased from 5.5% (w/w) at 5-cm depth to 7% (w/w) at 35-cm depth with differences between treatments being very small and usually not significant.

In 1984 topsoil penetration resistances of the recompaction treatments were generally lower or similar to that for the undisturbed hardpan while in 1985 all recompaction treatments had equal or higher penetration resistances than UR/0P. During the course of the experiment, the UR/0P plots showed evidence of structural improvement probably partly due to termite activity which was observed during sampling, particularly on the undisturbed plots. Topsoil bulk densities measured specifically at some plot areas with termite activity, were significantly lower than for the UR/0P treatment on average and similar to those after deep ripping.

Crop growth

In the first year following ripping (1984), grain yields were essentially independent of traffic treatments and were generally similar or larger for the ripped treatments than for the unripped UR/0P treatment (Fig. 2a). Yields in 1985 decreased significantly with increasing number of tractor passes. Of the ripped treatments only R/0P had a larger yield than UR/0P, with the 5P1/2 treatment producing the lowest yield (1.66-t/ha).

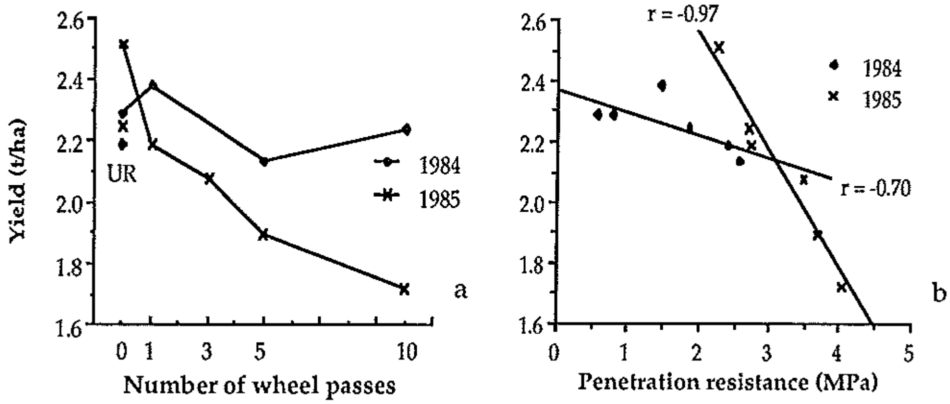

Fig. 2. (a) Variation of grain yield with number of tractor passes (the two single points show yield for the UR/0P treatment). (b) Correlation of grain yield with penetration resistance (13 August '84/'85 data) at 19-cm depth.

Figure 2b shows that yields in 1985 were correlated with penetration resistance at 19-cm depth (r = 0.97**), but not in 1984 (r = 0.70). This difference undoubtedly resulted from the variation in rainfall between the two years. In 1984 precipitation between 1 April and 31 May was 178-mm, with rainfall recorded on 21 days in May. The same period in 1985 had 65-mm of rain, with only 6 days in May with rainfall, of which 63% fell in one day. Although 1985 had sufficient rainfall later in the season, only the crop of the R/0P treatment seemed to have benefited and produced a significantly higher yield than in 1984.

Since the greatest constraint for root growth and plant establishment is the high soil strength of the hardpan layer, the effect of increasing traffic on yield is greater in years of moderate to high moisture stress. During the early stages of plant development under these conditions, root penetration through the compact hardpan is more severely restricted and the plant will subsequently be less efficient in utilizing subsoil nutrients and water.

CONCLUSIONS

(1) Disruption of a hardpan by deep ripping markedly decreased penetration resistance and bulk density. Deep ripping remained beneficial for following crops only if recompaction was avoided, e.g. by minimum tilling.

(2) Recompaction of the ripped soil by subsequent traffic together with age hardening, resulted in soil strengths exceeding that of the unripped soil.

(3) Under conditions of high moisture stress during the early stages of plant development excessive soil strength of the hardpan reformed by traffic, depressed grain yields even more than did the original hardpan.

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CONVENTIONAL AND ZERO TRAFFIC SYSTEMS COMPARED FOR WINTER BARLEY AND POTATOES

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ABSTRACT

Conventional machinery, modified to run on permanent tramlines at 2.8 m centres, allowed crops to be grown in traffic-free soil. Such a zero traffic system was compared with a conventional traffic system for four winter barley crops, under both ploughing and direct drilling, followed by a potato crop.

Appreciable advantages were found for the zero traffic system in terms of soil physical conditions, crop yield and draught requirement for primary cultivation. The magnitude of such effects varied markedly between seasons due to variations in weather patterns.

INTRODUCTION

Background

A previous traffic experiment with winter barley at SCAE (Campbell *et al.*, 1986) showed that increases in soil bulk density and cone resistance and decreases in air-filled porosity in the seedbed due to different numbers of wheel passes can produce lower plant populations and yields, although results varied with seasonal variations in the weather in the autumn and spring.

This paper reports an experiment in which four years of winter barley followed by one year of ware potatoes were grown to compare an experimental zero traffic system, in which conventional machines are all modified to run on permanent tramlines (2.8 m track), with a conventional traffic system based on conventional machinery on ploughed and, for the winter barley crop only, direct drilled seedbeds.

Site details

The experiment is located in Midlothian, Scotland, where the annual rainfall is 866 mm, the altitude 200 m and aspect south-east. The soil is a clay loam overlying a clay loam and is in Class 3 (2) of the Land Capability Classification (Bibby, 1982). This Class, limited by a slowly permeable subsoil, is described as capable of average cereal production, but with degrees of variability between years due mainly to interactions between climate, sowing and harvesting. Some soil physical properties are given by Campbell *et al.* (1986).

Treatments and experimental design

In the first year of barley, all seedbeds were ploughed while in the second year half were direct drilled. In the third and fourth years, the location of each traffic system was the same as in the second season. For the potato crop, all plots were ploughed as in the first barley year.

Each plot was 30 m long with the zero traffic plots being 9 m wide and the conventional traffic plots 8 m wide. In the zero traffic plots, there were three cropped strips separated by permanent unsown tramlines, each cropped strip being the 2.6 m working width of the 15 row seed drill or three unit potato planter.

Machinery and traffic system management

The zero traffic systems used a John Deere 4440 tractor with the track of the front and rear wheels modified to 2.8 m in conjunction with a chisel plough, powered cultivators, direct and conventional seed drills, a potato planter and a potato ridger, all with working widths of 2.6 m. The combine harvester had a 3 m cut width and the potato harvester was able to harvest individual potato ridges; both harvesters had their wheels modified to 2.8 m track. All wheels for the zero traffic systems ran outwith the cropped area. The conventional traffic systems used unmodified machinery and a conventional traffic pattern. Potato row width was 0.9 m giving three rows in each zero traffic cropped strip, the central row being free of traffic.

METHODS

Crop measurements

Plant populations were measured with a 0.1 m^2 quadrat about 10 days after emergence. The combine grain yield was measured for each zero traffic cropped strip and for the total area of each conventional traffic plot. Barley yields for the zero traffic systems were scaled up to correspond to those for a 12 m wide gantry system. Potato yields were obtained from the central traffic-free row in each zero traffic cropped strip.

Soil measurements

Soil dry bulk densities were measured with a high resolution gamma-ray probe (Henshall and Campbell, 1983), cone resistances with a recording penetrometer (O'Sullivan *et al.*, 1983), and soil volumetric water contents with a neutron probe (O'Sullivan, 1985). Relative diffusivities of minimally disturbed cores were measured using the method of Ball *et al.* (1983) and primary cultivation draught requirements by means of an instrumented tine dynamometer (Palmer and Glasbey, 1988).

RESULTS

Crop measurements

Table I shows that yields were generally heavier for the ploughed zero traffic system than for the ploughed conventional traffic system. There was little difference in yield between the two direct drilled traffic systems. However, seasonal variation in yield was large for all traffic systems, although the variation for the ploughed zero traffic system was the least. The yield of ware potatoes was heavier for the zero traffic system than for the conventional traffic system.

Winter barley establishment was always similar for the four traffic systems except that, in the fourth year, plant populations in the direct drilled systems were significantly smaller than in the ploughed traffic systems (Table I). There was no effect of sowing depth (40 mm). Seed potatoes were planted 50 mm below the original surface and at 300 mm spacing.

TABLE I Crop Measurements

	Winter Barley								Ware Potatoes
	Plants/m^2				Yield, t/ha				Yield, t/ha
	Year				Year				
	1	2	3	4	1	2	3	4	
Z_P*	303	386	349	355	6.3	8.01	6.97	6.64	59.3
Z_{DD}	-	402	361	261	-	8.08	7.00	4.38	-
C_P	304	398	346	344	4.8	7.93	6.09	6.37	51.1
C_{DD}	-	418	367	209	-	8.20	6.98	4.14	-
SE	10.7	13.7	14.9	20.8	0.11	0.23	0.23	0.59	0.60

* In all tables and Figs, Z = zero traffic; C = conventional traffic; P = ploughed and DD = direct drilled

Soil measurements

After the second barley crop was sown, the greatest soil dry bulk density was found in the direct drilled conventional traffic system below sowing depth. By harvest of the fourth barley crop, there had been no further increase in bulk density.

Generally, over the four years of barley, bulk densities between sowing depth and about 180 mm depth were ranked in order of decreasing bulk density as follows: direct drilled conventional traffic, direct drilled zero traffic, ploughed conventional traffic and ploughed zero traffic. Between 180 and 250 mm depth, the bulk density of the ploughed zero traffic system was markedly lower than that of the ploughed conventional traffic system. Seedbed bulk densities for all the traffic systems were similar for the first three barley seasons. In the fourth season, the seedbed bulk density of the direct drilled conventional traffic system was the greatest. Bulk densities of the soil in and below the centre of the potato ridges showed no differences at any depth.

For most traffic systems, there was a progressive increase in the relative diffusivity of minimally disturbed soil cores sampled at 35 and 100 mm depths and tested at -6 kPa matric potential (Fig. 1). The increase was more than 300% in the ploughed zero traffic soil and rather smaller in the ploughed conventional system. There were appreciable increases in the relative diffusivity of cores sampled from both direct drilled traffic systems, although relative diffusivities remained low even after three years of direct drilling. There was no difference in the relative diffusivities of cores sampled from the centre of the potato ridges from the zero and conventional traffic systems at field water content.

Soil volumetric water contents, measured with a neutron probe in the last two years of barley, showed no differences in water use by the crops in the four traffic systems or in the depth of soil from which water was extracted.

Mean draught forces for primary cultivation after the fourth year of winter barley (Table II) were lower for both ploughed and direct drilled zero traffic systems than for the conventional traffic systems. However, after potatoes, draught force in the conventional traffic system was almost 100% greater than in the zero traffic system.

Table II Mean draught force for a 12 m tramline system, kN

	After barley	After potatoes
Z_P	10.0	8.4
Z_{DD}	10.5	-
C_P	11.5	16.1
C_{DD}	12.4	-
SE	0.29	0.79

DISCUSSION

Annual mean winter barley yields, for the four traffic systems, ranged from 5.4 t/ha in the last year to 8.1 t/ha in the second year. However, soil dry bulk densities and cone resistances did not show annual changes which reflected such a variation in yield.

The bulk density of the soil in the direct drilled traffic systems did not change over the last three years of winter barley. However, soil structural improvement was indicated by the progressive increase in relative diffusivity over the three years, with greater percentage increases and final values found in the zero system. Despite this, yields of barley for both direct drilled systems in the third year were almost half those found in the first year of direct drilling. Yields in the third year were depressed by adverse spring rainfall of 322 mm (Fig. 2) which more than offset the effects of soil structural improvement in the direct drilled traffic systems. In general, barley yields decreased with increasing rainfall, but yields for ploughed systems were reduced to a lesser degree than those for direct drilled systems. In particular, seasonal variation in barley yield was smallest in the ploughed zero traffic system.

The effect of greater than long-term average rainfall in the fourth barley year is shown in Fig. 3, where air-filled porosities, which were calculated from soil volumetric water contents and bulk densities, are shown to be extremely low through the spring until early July. Although air-filled porosities were low for the soil in all traffic systems, the yields for the two ploughed traffic systems were heavier than those for the two direct drilled traffic systems. Greater relative diffusivity at rooting depth in such wet soil (Fig. 4), was probably responsible for heavier barley yields in the ploughed compared with the direct drilled traffic systems. The two outliers were excluded from the regression analysis.

There was a considerable variation in barley yield between the crop rows of the conventional traffic systems. This was in contrast to the relative uniformity of yield in the zero traffic systems in the seasons which had wetter than average spring weather. Yield reductions and later crop ripening were observed in locations which had received wheel traffic either at sowing or during seedbed preparation or in the temporary spraying tramlines.

Winter barley establishment in the first three years was satisfactory due to similar and satisfactory soil conditions in the seedbed for all four traffic systems. In the wet autumn of the second year, an adequate number of plants were established as the potential soil water deficit was over 70 mm due to the very high deficit during the summer and only 50 mm of rain prior to sowing. In contrast, the deficit when the third crop was sown was over 100 mm. However, due to an extremely wet summer prior to sowing the fourth crop (which caused lodging in the third crop), the deficit was only about 5 mm. Wet weather until mid-October then maintained a very low soil water deficit and air-filled porosities of less than 5% v/v below 90 mm depth, particularly for soil in both direct drilled traffic systems. Campbell *et al.* (1988) have reported reduced winter barley establishment due to transient water-logging in the seedbed.

CONCLUSIONS

1. The experimental ploughed zero traffic system gave the heaviest winter barley and ware potato yields. Barley ripeness was also very uniform.

2. Winter barley yields decreased with increasing rainfall. Such yield responses were related to aeration status in the root zone during the spring.

3. Winter barley emergence was depressed by transient water-logging under direct drilling.

4. Draught forces for primary cultivation after barley averaged about 14% less for the zero traffic systems than for the conventional traffic systems; after potatoes, the draught force for the zero traffic system was almost half that for the conventional traffic system.

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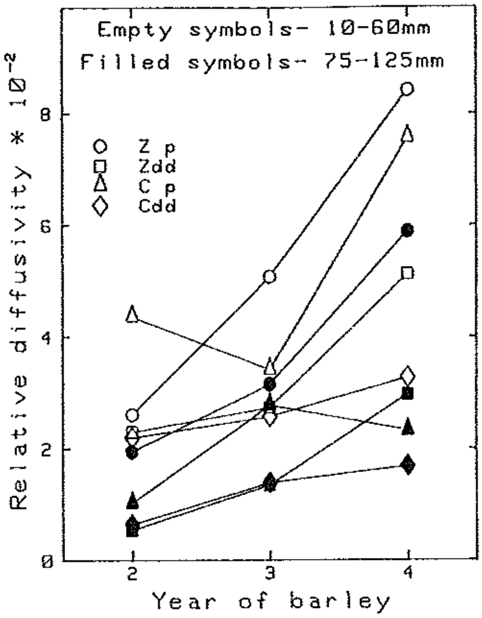

Fig.1. Variation of relative diffusivity with time.

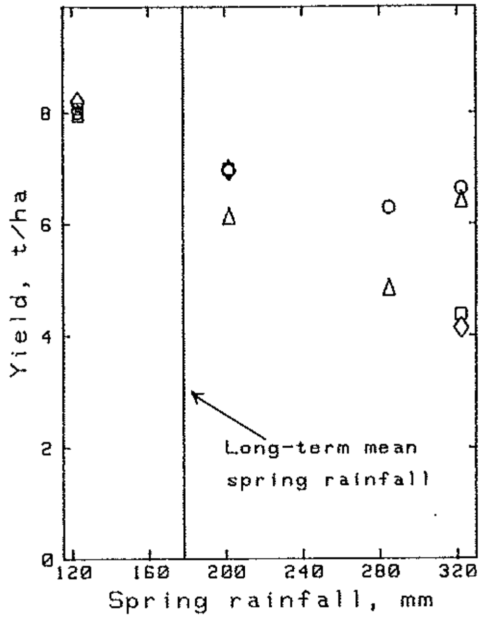

Fig.2. Variation of barley yield with spring rainfall.

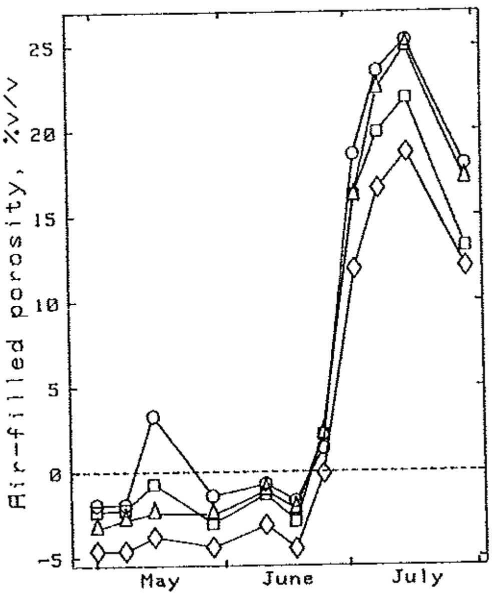

Fig.3. Variation of air-filled porosity at 200mm depth with time in the fourth year of barley.

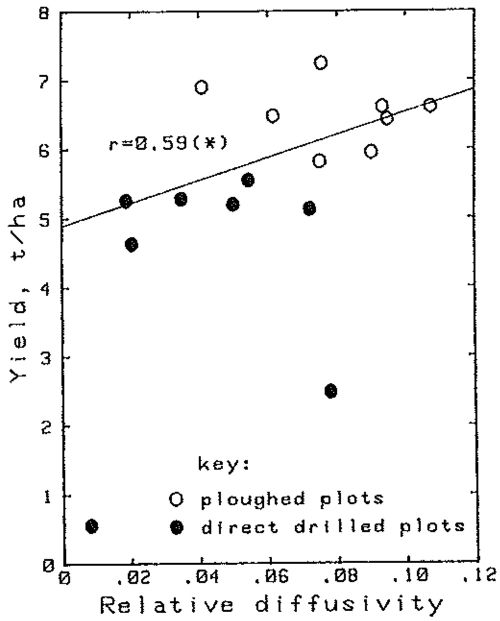

Fig.4. Variation of yield with relative diffusivity of cores centred at 35mm depth in the fourth year of barley.

CONVENTIONAL, LOW GROUND PRESSURE AND ZERO TRAFFIC SYSTEMS IN RYEGRASS GROWN FOR SILAGE

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ABSTRACT

In a full-scale systems experiment, on a clay loam sown in September 1985 with perennial ryegrass for silage cropping, conventional, low ground pressure and zero traffic were compared. During the first year, topsoil bulk density and strength were increased by both conventional and low ground pressure traffic compared with the traffic-free beds of the zero system. Less compaction, and across-plot variation in compaction, developed in low ground pressure plots than in those receiving conventional traffic; these differences persisted in the second season. Production of digestible organic matter and crude protein increased by 15 and 38 percent respectively in the absence of wheel traffic, and by 11 and 27 percent respectively when soil and sward damage were moderated by low ground pressure traffic. The major factor promoting yield differences was enhanced N-uptake from the less compact soil of the alternative systems.

INTRODUCTION

Research to date on compaction in grassland and the effects on productivity has yielded information on the outcome of single and multiple wheel passes, with various loads, on a range of grass species and varieties (eg. Eriksson et al, 1974; Luten and Roozeboom, 1976; Rasmussen and Moller, 1981). More recently, in Northern Ireland, Frost (1987) compared grass yields in wheel tracks produced by a tractor and slurry tanker fitted with different combinations and types of tyres; Frame (1987) reported reduced herbage yields in wheel tracks after cutting clover-ryegrass mixed swards. The conclusions in most of these experiments was that wheel traffic does reduce grass yields; however, in many of these studies only minimal short-term information on soil conditions and crop responses were presented and this limits the explanation of effects and the ability to make firm recommendations in respect of agricultural practice.

Here we report the results from the first two years of a long-term experiment designed to investigate the extent to which alternative levels of tyre/soil contact stress, low and zero, influence compaction and productivity compared with a conventional system.

EXPERIMENTAL DETAILS

Site, location and soil: The experiment was situated 10 km south of Edinburgh, Scotland where the average annual rainfall is 866 mm; long-term monthly averages and those for 1986 and 1987 are shown in Fig. 1. The site altitude is 200 m and the topography gently undulating. The soil is an imperfectly drained clay loam overlying clay loam of the Winton Series; organic matter content of the topsoil is 4.7 percent. Similar imperfectly drained soils in the surrounding region of Scotland are well suited to the production of grass for silage. Commonly, such land is retained under grass for periods of 2 to 7 years in rotation with cereals and potatoes; perennial ryegrass is the dominant species in the swards.

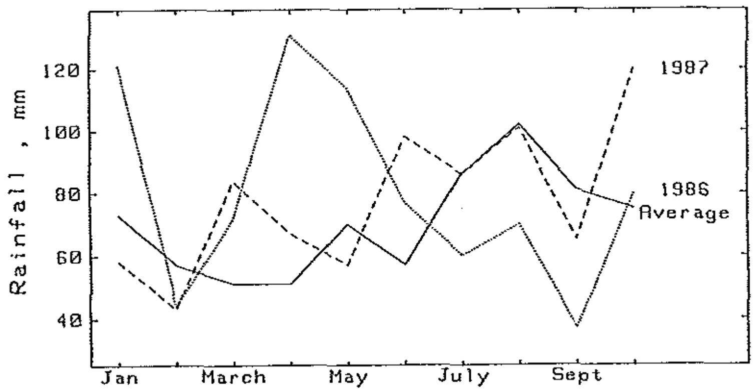

Fig. 1. Long-term average, 1986 and 1987 monthly rainfall in the locality of the experiment

Treatments and experimental design: There were four replications of three treatments; the treatments comprise conventional (C), low ground pressure (L) and zero (Z) traffic systems. For the C and L systems the plots were 30 m long by 20 m wide; the Z plots comprised seven traffic-free beds, each 30 m long by 2.4 m wide. The size of tractors and machinery used in C and L was typical of that used for silage production in Scotland: details of weights and tyre/soil contact stresses are given in Table 1. In the low ground pressure system, conventional tyres were replaced by commercially available larger-than-standard tyres for which recommended inflation pressures were relatively low. For the Z system, equipment was modified such that it could operate from permanently positioned wheel tracks at 2.8 m centres. In both the zero and low gound pressure systems, the pick-up reel of the forage harvester operated directly in-line behind the tractor, whereas in the conventional system the reel was off-set.

Fertiliser (NPK compound) was applied, using the appropriate system-designated tractor and a mounted 12 m spreader, in the spring at 120 kg/ha nitrogen and at 100 and 80 kg/ha nitrogen after first and second cuts.

Soil physical properties were measured by conventional methods, together with responses in crop yield, quality and uptake of nitrogen. Plot yields were measured at each harvest by recording trailer weights on micro-computer controlled portable weighing pads.

Table I Machinery and tyre/soil contact stress

Machine	Traffic system	Unladen weight, t	Mean tyre/soil contact stress, kPa
Tractor	Conventional (C)	3.87	Front 175, rear 102
	Low ground pressure (L)	4.14	Front 42, rear 30
Mower-conditioner	C	1.20	inner 58, outer 89
	L	1.20	inner 51, outer 72
Forage harvester	C	1.27	91 and 106
	L	1.02	66 and 61
Trailer	C	1.31	105
	L	1.50	75

RESULTS

Soil responses to the traffic systems.

Soil bulk density: After first harvest in the first season (1986), soil that received conventional or low ground pressure traffic during mowing and forage harvesting (i.e. the areas between cut swaths) had greater bulk density than areas that received no traffic. In the upper 0.12 m there was not a significant difference in soil response between C and L traffic systems; lower in the topsoil however there was greater compaction in C than in L, particularly where there had been a pass with the relatively full silage trailer. Measurements made after completion of the second and third harvests indicated significant differences in compaction between C, L and the zero traffic systems (Fig. 2). Profiles of soil bulk density measured in each system after first and third harvests in the second season (1987) did not differ significantly from the profiles exisisting at the end of the first season.

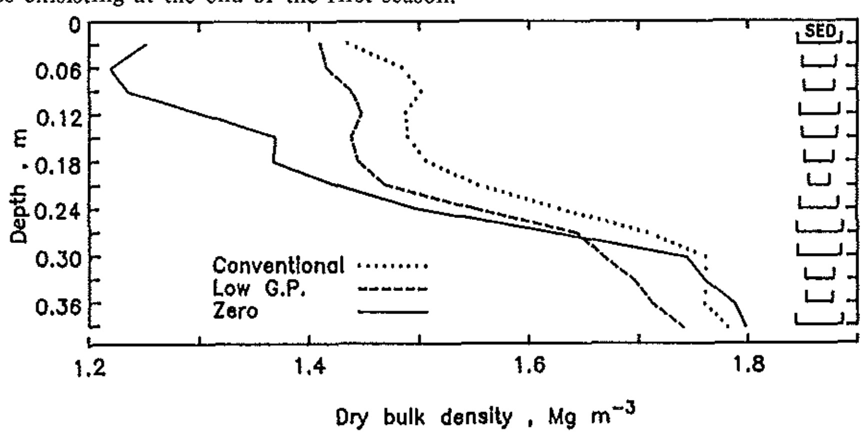

Fig. 2. Variation of soil bulk density with depth in C, L and Z systems after the third harvest, 1986

Vane shear strength: After each of the six harvests to date, mean vane shear strength close to the soil surface (measured by a 28 mm long x 19 mm diameter vane centred at 40 mm depth) in the conventional system was significantly greater and more variable than in the low ground pressure system, and each of these was significantly greater in strength than the soil in the zero traffic beds. After the third harvest in 1987, mean vane shear strength was 67, 53 and 29 kPa in C, L and Z respectively; transect (0.5 m interval) variability in the C and L system for that occasion is shown in Fig.3.

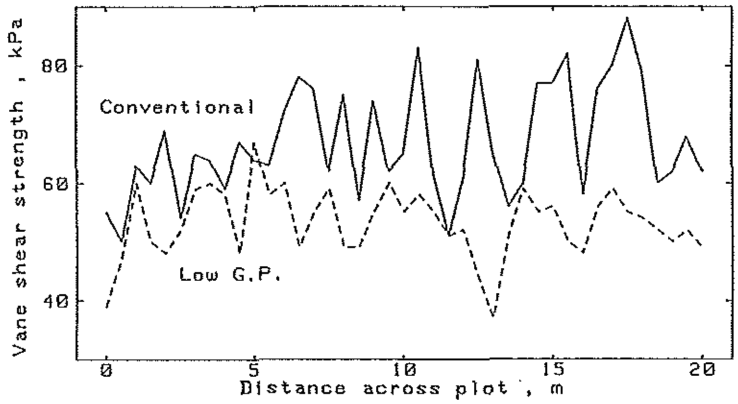

Fig. 3. Vane shear transects at 0.04 m depth (vane centre) after third harvest, 1987

Soil water content and potential: With the exception of the third cut in 1986, soil water content and potential at harvests were relatively high (Fig. 4). In 1986, soil water potential in the upper 0.2 m fell below tensiometer range (approx. <-80 kPa) during rain-free periods between first and second cut and before the third cut. Throughout the 1987 season, soil water potential remained within range of tensiometers.

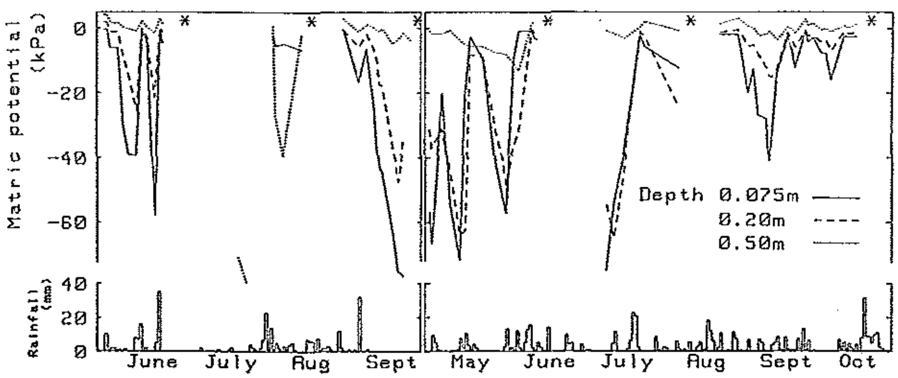

Fig. 4. Soil water matric potential in the conventional system during the growing season, 1986 (left) and 1987 (right), and daily rainfall, * indicates crop cut

Soil temperature: In the period March to mid-April 1987, average daily temperature was consistently lower (by 0.1 to 0.3^{o}C) at 50 mm depth in the soil of the conventional system than in the low ground pressure system. In the warmer period that followed from mid-April through May, however, temperatures were generally higher in C than in L. There was a similar pattern at 100 mm depth, though the cross-over did not occur until mid-May. Temperatures in the zero traffic soil varied above, below and between those in C and L.

Crop responses to the traffic systems:

Yields of dry matter (DM), digestible organic matter (DOM) and crude protein (CP) are given in Table II. In each year, the first cut was made for good quality silage between 40 and 70% ear emergence; second and third harvests were taken 6 and 13 weeks later. In the first season, total dry matter production did not differ significantly between traffic systems; however, the yield of DOM and CP was greater from L than from C, and CP yield was greater from the Z system than from C. In the second season, the alternative systems, L and Z, out-yielded the C system in all three components of yield at each cut. From the time of the second harvest in the first season, a characteristic of the conventional system was an unevenness in growth and coloration in the C crop compared to the more uniform sward in the low ground pressure system and, especially, in the crop of the zero traffic system.

Table II Yields of dry matter, digestible organic matter and crude protein

	Yield, t ha^{-1}											
	Dry matter				Digestible organic matter				Crude protein			
Cut	C	L	Z	lsd	C	L	Z	lsd	C	L	Z	lsd
1986 1	5.06	5.72	6.36	0.678	3.52	4.01	4.31	0.458	0.46	0.64	0.67	0.140
2	4.57	4.30	2.60	1.398	2.96	2.86	1.74	0.418	0.48	0.50	0.42	ns
3	1.30	1.70	2.22	0.298	1.00	1.29	1.69	0.226	0.20	0.27	0.36	0.055
Total	10.93	11.72	11.18	ns	7.48	8.16	7.74	0.608	1.14	1.41	1.45	0.170
1987 1	5.40	6.76	6.90	0.655	3.90	4.66	4.73	0.407	0.38	0.51	0.55	0.080
2	3.33	3.89	4.43	0.377	2.25	2.50	2.88	0.217	0.31	0.43	0.51	0.042
3	2.58	2.81	3.59	0.203	1.75	1.90	2.42	0.161	0.30	0.36	0.43	0.042
Total	11.31	13.46	14.92	1.026	7.90	9.06	10.03	0.629	0.99	1.30	1.49	0.094

Nitrogen uptake by the grass:

N-uptake was calculated from the nitrogen concentration in the herbage and the dry matter yield at each cut, and apparent recovery calculated as a proportion of the amount applied. At five of the six cuts to date, significantly more nitrogen was recovered from L and Z than from C; over two seasons, 57 percent was recovered from C compared with 72 and 79 percent from L and Z respectively. The greater uptake in Z and L was a product of higher N concentrations in the Z and L herbage as well as the heavier dry matter yield compared with the conventional system. Uptake, and grass growth, were diminished in wheeltracks in both C and L after the spring application of fertiliser in 1987; the reductions were greater in C than in L.

DISCUSSION

Over the two years of the experiment to date, the total yields of dry matter, and of the digestible organic matter and crude protein components, showed significant advantages from both zero and low ground pressure traffic compared with conventional traffic. In the first season, although DM yields were not significantly different overall, the zero system out-yielded the conventional traffic system in crude protein tonnage, and L out-yielded C in both DOM and CP. The low yield from Z at the second cut seemed to be closely related to the impaired regrowth during the unusually protracted period (3 weeks) without rainfall which followed application of fertiliser after the first cut: in all three systems the fertiliser granules remained intact on the soil surface during the rain-free period. It is likely that the relatively loose topsoil in the zero traffic beds was more depleted in both water and nutrients as a consequence of more vigorous growth prior to the first cut compared with the growth in the C and L systems. Light green coloration of the grass indicated below-optimum N uptake in Z. The heavier yield from the Z system at the third cut resulted from poorer growth generally in C and L, and particularly, in those areas that received wheel traffic at second harvest, when the upper 0.10 m of the soil was wet compared to conditions prevailing at the first and third harvest.

In the second season, when rainfall patterns were more typical of those for the region, the yields of DM, DOM and CP were greater in the novel traffic systems than in their conventional counterparts; consequently, both the amount and feeding value of the crop were enhanced. At second and third harvests, Z produced greater quantities of each of the yield components than the low ground pressure system.

Overall, therefore, there were strong indications that herbage production was increased when traffic was eliminated (Z) from the soil and sward and, to a lesser extent, when the compactive effects of traffic were moderated (L). The greater density of the soil in the C system compared to that in Z and L resulted in greater strength and lower temperatures in early spring: these conditions may have resulted in poorer root development. After spring fertiliser application, temperatures tended to be higher in the C soil and, in combination with higher water contents and lower air-filled porosities, may have lead to greater losses of N than occurred in Z and L by denitrification or through increased leaching or surface run-off. The close association, at the final cut in the first season and throughout the second season, between crop growth, nitrogen concentration in the herbage and the location of recent wheel traffic suggests that the effect of soil compaction and/or sward damage on uptake of nitrogen was a crucial factor in determining yield responses in the three systems. Availability of water to the crop would not have been a limitation to growth at any stage in the second season (Fig. 4). The breakage of leaves and stems or displacement of roots may have contributed to direct damage to the sward stubble by traffic at mowing and harvest but has not been evaluated as yet.

CONCLUSIONS

1. Damage to soil and sward was moderated, and yield and crop quality correspondingly enhanced, in the absence of wheel traffic and when tyre/soil contact stresses were reduced.
2. Smaller yields were associated with increased soil density and decreased uptake of nitrogen.
3. Increased recovery of nitrogen in the alternative traffic systems has important economic implications.

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MAIZE RESPONSE TO TRACTOR TRAFFIC FOR SEEDBED PREPARATION

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ABSTRACT

Compaction caused by tractor traffic during secondary tillage was studied in a field experiment. Twelve track- and wheel-type tractors were evaluated on a fine, montmorillonitic mesic, Typic Haplaquolls soil. Maize emergence, growth, and yield were significantly reduced by the tractor traffic. Soil bulk density, water content, and penetration resistance were greater in the tractor tracks. Track-type tractors tended to have less affect on soil conditions and maize growth than did wheel-type tractors.

INTRODUCTION

Studies in the Midwest have shown that soil compaction with heavy loads can have a detrimental effect on crop yields. Gaultney et al. (1982) observed over 50% yield reduction for maize grown in Indiana on severely compacted subsoils and about 25% yield reduction on moderately-compacted plots during relatively wet years. Voorhees and Lindstrom (1983) measured a 26% decrease in maize yield on plots subjected to 18.1 t per axle compaction wheel loads and 9% yield reduction on plots subjected to 9.1 t per axle loads when compared to plots receiving no more than 4.5 t per axle loads in a study at Waseca, Minnesota. Gameda et al. (1985) found that heavy axle loading of clay soil significantly delayed crop establishment and maturity and reduced plant growth. However, high axle loads had very little effect on plant growth and maturity in a loam soil. Smucker and Srivastava (1983) reported that compaction on two soil types caused soybean yield reductions as great as 0.43 t/ha. However, compaction is not always detrimental. For example, Voorhees (1983) found that for drier conditions in the northern Corn Belt, soybeans yielded better in rows adjacent to wheel tracks.

Wheel tracks from secondary tillage operations often cause slower growth and a generally poor appearance of plants in the wheel tracks. The objectives of this research were to:

1. Evaluate the compaction caused by track-type and wheel-type tractors during tillage for seedbed preparation.
2. Determine the effect on maize growth and yield of compaction caused by tractors during secondary tillage.

METHODS AND MATERIALS

The experiment was conducted on a fine, montmorillonitic, mesic, Typic Haplaquolls (Chequest silty clay loam) soil located in the Mississippi River floodplain in southeast Iowa. The soil has approximately 38% sand, 34% silt, and 28% clay. This area was selected because there had been evidence of reduced crop growth in tracks of vehicles used for spring tillage and chemical application.

The compaction treatments were arranged in a randomized complete block design with 3 replications in 1984 and 6 replications in 1985, 1986, and 1987. Each plot was arranged as shown in Figure 1. Metal bench mark stakes, used to accurately locate the plots each year, were driven into the soil beneath the depth of moldboard plowing. Bench marks were found by use of surveying instruments and metal detector.

Each plot was tilled with one pass of a field cultivator pulled by the tractor assigned to that plot. The paths followed by the tractor tracks or wheels were carefully marked. Tillage was done to a 10 cm depth with a 9.8 m wide field cultivator. Soil samples were taken to determine the soil-profile water content at the time of compaction. After tilling, maize was planted, perpendicular to the tillage direction, by using a 16 row planter. Rows were planted on 76 cm spacings. After planting, the subplots (Figure 1) to be used for maize growth and soil condition measurements were marked with wooden stakes. Equal sized areas in the trafficked and the untrafficked portion of each plot were marked. The subplots for maize growth measurements were 4 rows long and as wide as the tire or track used in that treatment. Soil condition measurements were made in one row subplots as wide as the tire or track. Weeds were controlled with herbicides and without cultivation. After harvest the plots were moldboard plowed in the direction of the rows and disk harrowed.

Each year, soil bulk density, water content, and penetration resistance were measured after maize had emerged. Samples for bulk density determination were taken by use of core sampler similar to that described by Buchele (1961). The sampler is mounted on a tractor three-point hitch. Soil cores 7.6 cm in diameter were taken. Cores were taken in the tractor tracks made during secondary tillage and in the untrafficked area. The cores were sectioned into 5-cm depth increments. Soil penetration resistance was measured by use of a Chatillon Model DFG-100 digital force gage and a 12.7 mm diameter cone penetrometer. The penetrometer was pushed by hand into the soil.

Maize plant response was evaluated by measuring rate of stand establishment, plant population, plant height, barren plants, yield, and grain moisture content at harvest. The rate of stand establishment was estimated by calculating an emergence rate index (ERI) (Erbach, 1982). The number of plants emerged in each staked wheel track and nontracked area were counted on several days during the emergence period. The extended leaf height of each maize plant in four trafficked rows and in four nontrafficked rows of each plot were measured. Meter sticks were used to measure the plant heights to the nearest one-half centimeter. Plots were hand harvested. The maize was shelled and weighed. The number of plants in each plot and the number of barren plants in each plot were counted at harvest time.

RESULTS AND DISCUSSION

Maize growth

Growth of maize planted in the tracks of the tractor pulling the field cultivator was reduced relative to growth in the non-trafficked areas (Table 1). Maize emerged slower in the tracks from each tractor than it did from the adjacent untrafficked area. During the four years of the study, maize in the tractor tracks had an average 10% lower emergence rate index than the maize in the untrafficked areas, although final plant population was not greatly affected by the tractor traffic. Tractor traffic reduced plant height by an average of 6%, and caused an average yield reduction of 13%. In three of the four years there was an increase in grain moisture content at harvest in the tracked areas.

In the tracks, ERI was 6% greater for track-type tractors than for wheel-type tractors (Table 2). The type of tractive device had little effect on plant population except in 1987 when track-type tractors improved emergence in dry conditions. Maize in the track-type tractor tracks was an average of 9 cm taller than that in the wheel-type tractor tracks, and had a 7% greater yield. The type of tractive device had little effect on grain moisture content at harvest.

Soil conditions

Soil in the top 30 cm of the profile was denser, wetter, and more resistant to penetration in the tractor tracks than in the non-trafficked areas. These effects are as expected and relate closely to the plant growth responses shown in Table 1.

Soil condition differences between the averages of the track-type and wheel-type tractors studied were not great but indicated a consistently lower bulk density and lower soil water content in the tracks of the track-type tractors. Penetration resistance did not show consistent differences among tractive devices. Soil condition differences again relate closely to the plant response.

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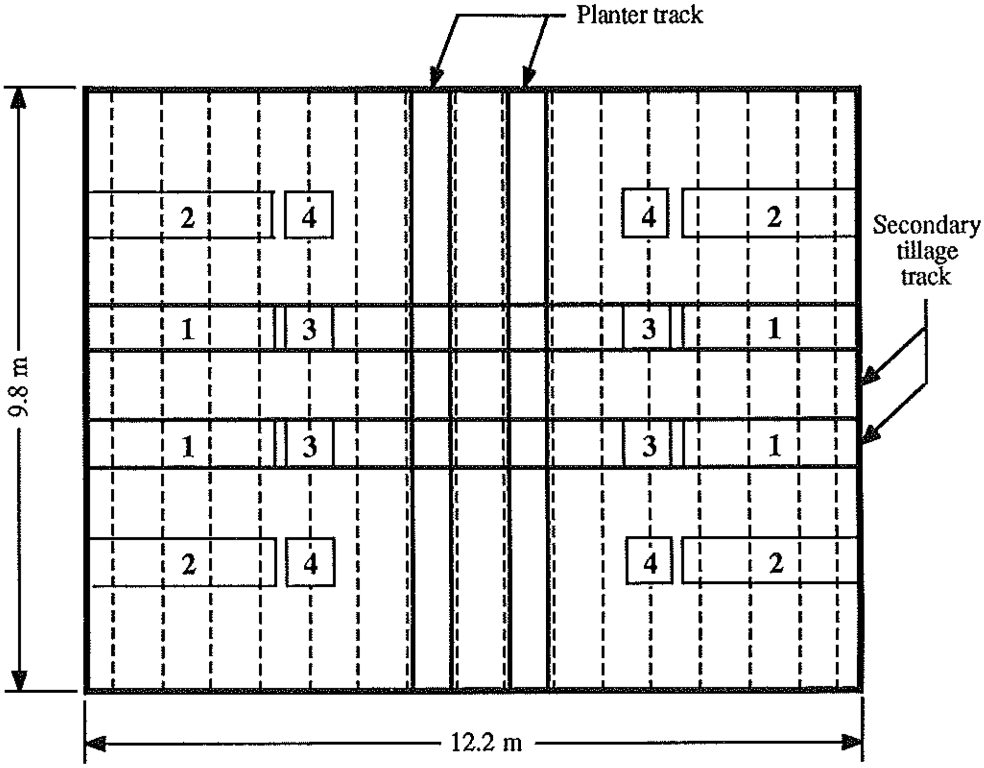
Table 1. Effect of tractor track on maize growth

Year	Location	ERI	Plant Population		Plant height	Yield	Grain moisture
			Emerged	Harvest			
		%/d	---plants/ha---		cm	t/ha	% wb
1984							
	Tractor track	6.7	57700	59600	178	9.5	22.9
	Non-track	7.8	61100	62700	194	11.4	21.8
	LSD (P=0.05)	0.30	940	NS	3.9	0.57	0.46
1985							
	Tractor track	11.6	58000	60400	---	10.8	18.1
	Non-track	13.3	60100	58700	---	12.2	17.5
	LSD (P=0.05)	0.30	1260	1480		0.27	0.17
1986							
	Tractor track	12.4	52900	53400	227	10.2	17.2
	Non-track	12.7	54100	52800	233	10.8	16.8
	LSD (P=0.05)	0.24	1100	NS	2.1	0.25	0.22
1987							
	Tractor track	7.2	55600	56300	---	5.4	25.5
	Non-track	8.3	57000	57800	---	7.1	26.1
	LSD (P=0.05)	0.25	1980	1320		0.22	0.42
Average							
	Tractor track	9.5	56000	57400	202	9.0	20.9
	Non-track	10.5	58100	58000	214	10.4	20.6
	Response in tractor track as percentage of non-track value	90	96	99	94	87	101

Table 2. Maize growth as affected by type of tractive device

Year Tractive device	ERI	Plant Population Emerged	Plant Population Harvest	Plant height	Yield	Grain moisture
	%/d	plants/ha	plants/ha	cm	t/ha	% wb
1984						
Track	7.1(93)*	54900 (97)	59500 (98)	185(96)	9.8(87)	22.9(106)
Wheel	6.3(79)	54100 (92)	59600 (92)	172(88)	9.2(79)	22.9(104)
1985						
Track	11.9(90)	57900 (96)	60400(104)	---	11.4(91)	18.0(103)
Wheel	11.3(84)	58000 (96)	60400(101)	---	10.7(84)	18.2(104)
1986						
Track	12.4(98)	52700 (98)	52900(101)	229(99)	10.2(97)	17.0(100)
Wheel	12.5(97)	53200 (97)	53900(101)	223(95)	10.0(91)	17.4(104)
1987						
Track	7.6(90)	67400(118)	57500(100)	---	5.6(81)	25.3 (98)
Wheel	6.8(82)	54000 (95)	54600 (94)	---	5.0(68)	25.4 (96)
Average						
Track	9.8(93)	58200(102)	57600(101)	207(98)	9.3(89)	20.8(102)
Wheel	9.2(86)	54800 (95)	57100 (97)	198(92)	8.7(80)	21.0(102)
Response for track as percentage of that for wheel						
	106	106	101	105	107	99

* Numbers in parentheses are the percentage that the value measured in the trafficked area is of that measured in the untrafficked areas of the corresponding plots.



(1) Area in tractor tracks from which plant measurements were taken.
(2) Untracked area from which plant measurements were taken.
(3) Area in tractor tracks from which soil measurements were taken.
(4) Untracked area from which soil measurements were taken.

Figure 1. Track and sample area locations in each experimental unit.

THE EFFECT OF TRAFFIC AND OTHER FACTORS ON WHEAT YIELDS IN SOUTH AUSTRALIA

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ABSTRACT

In 1983, wheat yields from the centre sections of plots in a tillage experiment begun in 1978 at Lameroo, South Australia were reduced by as much as 24 percent. These sections (4 m wide) were the pathways of tractors, an air seeder hopper and a boom spray unit, for field operations during the 1978-83 period. Any adverse effect of traffic on yields in earlier years had been relatively minor. Estimates of cumulative axle loading and localised ground pressure across the traffic zone have been made. There was an overall negative relationship between cumulative traffic and yields. However, wind erosion in 1982, nitrogen, and root diseases also had significant effects on yield. Confounding effects of variable soil water suctions and soil texture on measurements of compaction associated with traffic are discussed.

INTRODUCTION

The results reported in this paper have come from one of several field experiments set up in 1978 to test the postulate that production from conservation farming systems based would at least equal those from conventional systems.

In the present experiment, farm sized equipment was used for all operations on large plots (30m x 280m). All wheeled traffic associated with cultivation, seeding and spraying was confined to the centre section (4m) of each plot. The effect of this traffic on crop production was minimal until 1983, when clear reductions in crop vigour and grain yields were evident on some plots. The 1983 results have been used to test the postulate that the adverse effects of wheeled traffic on crop production are proportional to the cumulative number of passes of equipment, and the associated tyre loading and localised ground pressure.

METHODS

Design and treatments: The experiment was a 12x(2)x(2) split-split-plot with two replicates and two phases of each rotation. The 12 main treatments comprised tillage and rotation systems. The tillage treatments were cultivation only (C), or reduced tillage together with herbicides (RT); stubble residues were burnt (B), incorporated (SI), or retained on the surface (SR); from 1979 all seeding was done with an air seeder (A/S) with full cultivation. The rotations

TABLE I. Details of tractors, air seeder hopper, and spray boom unit used on a tillage experiment at Lameroo, S.A.; 1987-83.

EQUIPMENT		TYRE NUMBER		TYRE-PRESSURE		WHEEL-WIDTH		BETWEEN-WHEELS		LOAD-PER-AXLE	
		Front	Back	Front (KPa)	Back (KPa)	Front (cm)	Back (cm)	Front (cm)	Back (cm)	Front (t)	Back (t)
CASE 2470	= LT:	24.5/32	24.5/32	63	63	60	60	136	136	5.1	3.4
CASE 1490	= ST:	1200/16	18.4/30	167	120	25	46	88	109	1.5	3.5
SHEARER AIR SEEDER	=A/S:	none	1400/16	-	180	-	36	-	197	-	4.0
ROGER'S RURAL BOOM SPRAY	=B/S:	none	1200/16	-	180	-	25	-	88	-	4.0

Note: The axle loadings for the air seeder hopper and the boom spray unit are the maximum static values.

TABLE II. Distribution of total passes, static axle loading, and locallised ground pressure across the traffic pathway on plots with contrasting tillage treatments at Lameroo, S.A.; 1978-83.

TILLAGE AND ROTATION	TOTAL PASSES				DISTANCE FROM CENTRE OF TRAFFIC PATHWAY (CM)									
	LT	A/S	ST	B/S	60-75	75-90	90-105	105-120	120-135	135-150	150-165	165-180	180-195	Mean /15cm
					Total Number of Passes									
RT, W-vp	9	4	8	8	24	42	26	26	18	0	0	4	4	16
C,B; W-B-sM	32	8	10	10	30	94	74	74	64	0	0	8	8	39
					Total Static Load (t per 15cm of tyre width; max. values for A/S and B/S)									
RT, W-vp	9	4	8	8	29	48	26	26	19	0	0	8	8	18
C,B; W-B-sM	32	8	10	10	36	104	77	77	68	0	0	16	16	44
					Total Locallised Ground Pressure (KPa/100 per 15cm of tyre width)									
RT, W-vp	9	4	8	8	24	29	8	8	4	0	0	5	5	9
C,B; W-B-sM	32	8	10	10	31	46	20	20	15	0	0	11	11	17

Abbreviations: LT, Large Tractor; A/S, Air Seeder Hopper; ST, Small Tractor; B/S, Boom Spray tank.
See Methods and Table 1 for further details.

were wheat-volunteer pasture (W-vp), wheat-barley-sown medic pasture (W-B-sM), wheat-volunteer pasture/long fallow (W-LF), wheat-sown medic/long fallow (W-sM/LF).

The sub-treatments were nitrogen (N) at 0 or 35 kg/ha; from 1979, the nitrogen applied using the air seeder (cultivation with harrows only) within 1-2 days after seeding. The sub-sub-treatments were a nematicide (Nem) at 0 or 3.7 l/ha of Nemadi(R) for the control of Cereal Cyst Nematode (CCN; Heterodera avenae). With or without wheel tracks (+WT, -WT) were also treated as sub-sub-plots for statistical analyses; the nematicide was a basal treatment for this comparison.

Soil: Sandy loam over clay. Soil properties in the 0-10 cm interval compared with the subsoil were, - sand:silt:clay 90:2:8 of 50:6:45; pH, 8.6 cf 9.8; $CaCO_3$, 2.5 cf 20%; examples of contrasting soil moisture and soil strength profiles are given in Table IV.

Measurements: Soil samples (0-85cm) were taken on June 1, 1983 (2 weeks after seeding) for water content determinations (Fawcett et al., 1987), and associated soil strength measurements were made with recording penetrometer (Fawcett, 1977). Grain yields from the sub-sub-plots were obtained with a Massey 31 autoheader (1.8m x 40m area). The incidence of wind erosion in 1982-83, and treatment effects on crop growth were recorded in 1983.

Field equipment: Details of the large and small tractors (LT,ST), boom spray (B/S) and air seeder (A/S) are given in Table I. The cumulative number of passes by the equipment from 1978 to 1983, together with the data in Table I were used to calculate cumulative total values of the maximum static axle (assumed to be 1.5 x nominal operating tyre pressure; C. Norris, pers. comm.). See Tables II, III and IV.

RESULTS

A summary of the results are given in Table III. Extensive wind erosion occurred on some plots, particularly in the traffic zone, during the drought conditions of 1982-March 1983. This was associated with depressed and uneven crop growth in 1983. The overall yield responses to nitrogen and the nematicide, and depressions on the wheel tracks, were significant (P=0.05).

DISCUSSION

The results give some support to the postulate that crop production is negatively related to the cumulative wheeled traffic. Nevertheless, reductions in wheat yields on the wheel track zone of as much as 24 percent show that the wheeled traffic and/or associated factors can have substantial adverse effects on crop growth in some seasons. In 1984, a poorer season, crop yields ranged from 0.5 to 2.9 t/ha (the

TABLE III. The growth and grain yield of wheat in relation to wheel traffic (1978-1983), nitrogen, a nematicide, tillage and rotation systems, at Lameroo, SA. in 1983.

ROTATION AND TILLAGE SYSTEM	CUMULATIVE (1978-83) (Mean/15cm)			WIND EROS	CROP GROWTH	GRAIN YIELD: WT x N (+NEM)				CCN Score (0-5)	GRAIN YIELD: NEM x N (-WT)			
						% Loss		(t/ha)			% Gain		(t/ha)	
	PS	LD	LGP			+WT -N	+WT +N	-WT -N	-WT +N		+NEM -N	+NEM +N	-NEM -N	-NEM +N
Wheat - Volunteer Pasture (Phase 1)														
RT	16	18	9		n,C	-5	-16*	2.95	3.29	2.5	7	-1	2.76	3.32
RT	16	18	9		N	-7	-10	3.43	3.77	3.3	-1	0	3.47	3.78
C,SI	25	28	10		n,C	-7	-13	3.21	3.56	5.0	24*	19	2.59	2.98
C,B	25	28	10	T	n,C	-18*	-20*	3.49	3.59	5.0	4	13	3.37	3.18
Wheat - Long Fallow (Phase 1)														
RT,SR	33	36	12		n,C	2	-11	2.95	3.09	4.3	6	12	2.78	2.77
C,SR	33	36	12		N,C	-6	-5	2.98	3.29	4.5	38*	2	2.16	3.21
Wheat - Sown Medic/Long Fallow (Phase 1)														
RT,SR	37	42	18	T	n,c	-23*	-17*	3.66	3.91	4.8	24*	8	2.96	3.63
C,SR	39	44	18	T	n,c,U	-14	-16*	3.18	3.71	4.5	10	0	2.88	3.72
								(LSD:0.50,0.63)					(LSD:0.58,0.71)	
Wheat - Barley - Sown Medic Pasture (Phase 2)														
RT,SR	25	31	16	P,t	N	-4	-2	3.18	3.71	1.0	7	3	2.97	3.60
RT,SR	24	30	15	P,t	N,-,U	-9	-10	2.94	3.43	0.8	-8	8	3.19	3.17
C,SI	36	43	17	P,T	N,c,U	-8	-21	2.88	3.15	1.5	1	-1	2.86	3.17
C,B	37	44	17	P,T	N,-,U	-24*	-24*	3.06	3.22	1.0	-6	2	3.24	3.17
								(LSD:0.64,1.75)					(LSD:0.55,1.76)	

Abbreviations:

W/EROS : Obvious wind erosion along wheel tracks (T,t), or over much of the plot (P), in 1982-83.

CROP GROWTH : Obvious responses to applied nitrogen (N,n) and a nematicide (C,c); Uneven or patchy growth (U); t,n,c : Less pronounced effects.

CCN : Bioassay ratings of Cereal Cyst Nematode numbers in the soil (by courtesy, Agchem Pty Ltd., S.A.)

LSD : LSD (P=0.05): x,y =values for yield differences between N (same Tillage), and Tillage (same N), within either Phase 1 or Phase 2; * = change significant at P=0.05.

PS,LD,LGP : Cumulative Passes, Static Loading, and Localised Ground Pressure; average per 15cm of the traffic zone, 60-195cm from the centre of the pathway.

See the Methods section for further details.

TABLE IV. Examples of profile changes in soil strength and associated water contents at Lameroo, SA; June 1, 1983.

TILLAGE, ROTATION, CROP, 1983	DEPTH INTERVAL (CM) 0-10	10-25	25-40	40-55	55-70	70-85
Maximum Soil Resistance to a Cone Penetrometer (kgf)						
C,SI ; W-B-sM; W	22	32	39	39	23	13
RT,SR; W-B-sM; W	15	31	35	46	>50	-
C,SR ; W-B-sM; W	31	46	48	50	>50	-
C,SI ; W-vp ; vp	50	>50	-	-	-	-
Soil Water Suction (kPa)						
C,SI ; W-B-sM; W	18	17	17	20	23	32
RT,SR; W-B-sM; W	13	26	25	45	60	100
C,SR ; W-B-sM; W	54	89	51	50	72	195
C,SI ; W-vp ; vp	79	617	501	309	355	501
Soil Water Content (% oven dry basis)						
C,SI ; W-B-sM; W	14	24	22	26	26	27
RT,SR; W-B-sM; W	8	19	23	28	28	22
C,SR ; W-B-sM; W	6	16	19	26	21	19
C,SI ; W-vp ; vp	5	12	16	18	20	19
Soil Water Content at 10 kPa suction (% oven dry basis)						
C,SI ; W-B-sM; W	16	27	25	29	30	32
RT,SR; W-B-sM; W	9	24	28	35	38	32
C,SR ; W-B-sM; W	11	23	27	33	30	31
C,SI ; W-vp ; vp	11	25	27	30	35	33
Soil Water Content at 1500 kPa suction (% oven dry basis)						
C,SI ; W-B-sM; W	6	10	12	12	13	15
RT,SR; W-B-sM; W	2	9	11	17	17	14
C,SR ; W-B-sM; W	3	11	10	15	13	14
C,SI ; W-vp ; vp	3	11	13	14	16	16
Available soil Water (mm)						
C,SI ; W-B-sM; W	10	29	22	29	28	26
RT,SR; W-B-sM; W	8	24	28	23	24	18
C,SR ; W-B-sM; W	4	10	18	20	17	13
C,SI ; W-vp ; vp	3	4	5	8	9	7

For further details see the Methods section.

latter on long fallow) and the relative reductions in yield associated with wheel tracks were mostly less than 6 percent but reductions of up to 20 percent did occur.

While the pulverising effect of tractor wheels on dry sandy soils and the increased susceptibility to wind erosion was clearly demonstrated during the drought conditions of 1982, the effect of the traffic on soil compaction is unclear. Detailed assessments of compaction in the traffic zone have not yet been attempted at this site because of the confounding effects of soil water suction (Table IV) and variability in texture on soil strength. Soil strength measurements would need to be made in those seasons when the profile has been wet to relatively low suctions if these effects are to be minimised. The estimates of the distribution of axle loadings and localised ground pressures across the traffic zone give an indication of the extent of likely soil compaction (Table II).

Some crop damage by wheel traffic would also have occurred during the spraying of herbicides, while these and other results show that nitrogen availability and cereal root diseases are also affecting production.

CONCLUSIONS

Wheat yields can be substantially reduced along pathways where traffic is concentrated. Further research is needed to understand the relative importance of adverse effects of traffic associated with various seasonal conditions compared with those that are related to the cumulative effects of traffic. This has practical implications both for general broad-scale cropping as well as for controlled traffic on large cropping areas.

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SOIL STRUCTURE AND CROP RESPONSE UNDER HEAVY AXLE LOAD COMPACTION

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ABSTRACT

The effects of compactive loads of 10 and 18 t/axle, soil conditioning and subsoiling on soil pore size distribution were studied in a clay textured soil. Heavy axle loading significantly shifted pore size distribution to smaller pores. The effect of the soil conditioner in improving pore size distribution decreased with the level of prior compaction. The subsoiler had marginal effect in relieving compaction. Crop response directly correlated with pore size distributions under the various treatments.

INTRODUCTION

Soil degradation, structural damage and crop yield reductions are taking place due to the progressively increasing size of agricultural vehicles and the intensive manipulation of soils. As a result, soil compaction is no longer limited to the topsoil where it can be eliminated or alleviated by tillage, but extends into the subsoil (Hakansson, 1982) where it can persist over long durations (Voorhees et al., 1986; Gameda et al., 1987).

Among the numerous studies carried out to determine the effects of wheel traffic on soils, parameters such as bulk density, soil strength, total porosity and hydraulic conductivity have been used as indicators of soil compaction, with bulk density being the most widely used (Bateman, 1963; Raghavan et al., 1978; De Kimpe et al., 1981; Voorhees et al., 1986; Gupta and Allmaras, 1987). However, parameters such as bulk density are not always the best indicators of soil structure. For example, despite persistent high soil bulk density or strength, crop response can improve with time as a result of soil structural changes stemming from biological activities or weather conditions (Hakansson, 1982). Conversely, previous findings suggest that small changes in density can lead to much greater changes in crop yields (Gameda et al., 1985). The reason for this is likely that total porosity is not the only important parameter affecting crop growth, but that the size and distribution of existing pores are also significant for crop response.

Thus, although total porosity can describe the damage to soil structure resulting from compaction, pore sizes and their relative abundance would provide additional information to describe these structural changes. Vomocil and Flocker (1961) considered the determination of pore size distribution as one of the most useful estimates of soil compaction. This is because different pore sizes have different significance in terms of plant growth and soil hydraulic properties. For example, the reduction in total porosity resulting from compaction would lead to a shortage of oxygen for plant roots while the reduction in pore diameter would prevent the entrance of root tips and the easy flow of gravitational water (Ide et al., 1984).

Subsoiling is usually conducted to relieve compaction below the plow depth. It aims at enlarging the root zone by easing root penetration (Vepraskas and Miner, 1986) and by permitting a larger volume of soil to be used by plants for water and nutrients (Ide et al., 1984). Subsoiling can also increase transmission porosity, that is, pores between 50 and 500 μm (Negi et al., 1982).

Crop response to subsoiling can be complex. This response is at times positive (Dumas et al., 1975; Negi et al., 1980) but it is not consistent in wet years or in soils that are poorly drained (Cassell and Edwards, 1985; Ide et al., 1984). The benefits of subsoiling also tend to be of short duration and a subsoiled field can easily be recompacted by traffic (Hartge and Sommer, 1980). This varied response can perhaps be better understood if the effects of subsoiling in relieving subsoil compaction can be described by determining the resulting changes in pore size distribution.

Accordingly, our study evaluates changes in bulk density and pore size distribution incurred by heavy axle loading, soil conditioning and subsoiling treatments. It also carries out comparisons with relative yields and discusses the effect of these parameters on crop response.

MATERIALS AND METHODS

The experiment was conducted on a clay soil (35% clay, 22% silt, 43% sand) at Macdonald College of McGill University. The field has been repeatedly compacted, with loads applied in April and November 1982, October 1983, May 1985 and May 1986. A three-axled, four-wheel drive, D330 off-road vehicle was used to apply loads of 10 and 18 t/axle on 5m x 20m plots. Loads on control plots were limited to less than 5 t/axle. The 10 and 18 t/axle loads were applied over the total area of plots to be compacted. The field was annually seeded to grain corn.

In the spring of 1987 the soil was treated with a chemical conditioner and deep tilled with a narrow tined (63.5mm) subsoiler. The chemical conditioner which was applied was a non-ionic surfactant with an active ingredient of 28% linear alkyl alkoxylates. The chemical conditioner was mixed at a 10% concentration with water and the mixture was applied at a rate of 10 L/ha. The subsoiler was pulled with a 4WD John Deere 2150 tractor at an average depth of 0.5m. Subsoiling was carried out eight weeks after seeding between alternate corn rows within a plot. Soil moisture content during subsoiling ranged between 15 and 19% (w/w).

The pore size distribution for each treatment was determined for three layers (0-0.2m, 0.2-0.4m, 0.4-0.6m) from water desorption curves using the capillary rise equation. Values were obtained with a pressure plate apparatus for the -100 kPa potential and with Haynes funnels for potentials of approximately -1.5, -4.0 and -10 kPa. Six soil samples (three for the Haynes funnels and three for the pressure plates) consisting of 73mm diameter by 32mm cores were taken from each layer. Sampling was carried out on one site per plot.

RESULTS AND DISCUSSION

Heavy axle loading, soil conditioning and subsoiling significantly affected the proportion of pores greater than 200, 75, 30 and 3 μm throughout the soil profile under investigation (Table I). When only looking at the effects of the 10 and 18 t/axle loads several interesting observations can be made. In the topsoil (0 to 0.2m), the 10 t/axle load tended to lead to greater compaction. In fact, differences due to the 10 t/axle load were between 11.4 to 27.3% greater than those due to the 18 t/axle load over the 3 to 75 μm pore size range. This trend was reversed for pores greater than 200 μm. In the shallow subsoil (0.2 - 0.4m), both loading levels led to significant compaction with the effect of the 18 t/axle load predominating. In the deeper subsoil (0.4 - 0.6m), the effect of the 18 t/axle loading was over 32% greater than that of the 10 t/axle treatment for the 30 to 200 μm range.

When considering treatments carried out to alleviate the effects of the compactive loads, what is of interest is that, in the topsoil, the subsoiler alleviated compaction in control plots and in those compacted with the 18 t/axle loading. In the shallow subsoil, its effect was limited to that of the 18 t/axle loading, and in the deeper subsoil, it had no effect on any of the compactive treatments. The use of the subsoiler in plots subjected to the 10 t/axle load showed that its effect was detrimental rather than beneficial throughout the soil profile under investigation. The reasons for this are not clear.

The effect of the chemical soil conditioner tended to decrease with the level of prior compaction, that is, it was more effective in control plots than in those subjected to 10 or 18 t/axle loads. However, caution should be exercised when determining the efficacy of the chemical conditioner in increasing soil porosity. It is more likely that its effect is limited to altering water desorption characteristics rather than actually changing soil pore sizes.

The subsoiling treatment had a detrimental effect on crop yields in uncompacted plots and in those subjected to the 10 t/axle loading, and had no effect in plots treated with the 18 t/axle load. The soil conditioner had no effect in improving yields in control or 18 t/axle plots, but it marginally increased yields in plots treated with the 10 t/axle load. Typical relationships between pores size distribution and crop yields are shown in Figure 1.

Crop responses to the various treatments showed that there were significant correlations between total plant dry matter yield and pore size distributions at depths between 0.2 and 0.6m (Table II). In contrast, there was no significant correlation between plant yield and total porosity, that is, density. Grain yields showed no correlation with either pore size distributions or total porosity.

These findings emphasize the need to accompany density measurements with parameters such as pore size distribution in order to describe agricultural soil compaction. Similarly, they point out that, apart from soil structure, parameters such as oxygen and nutrient availability and uptake need to be considered in order to have an even better accounting of crop yields.

TABLE I. Mean values of the percentage of pores larger than given pore diameters, total porosity and crop yields.

		Pore Size (μm)					Relative Yields	
Depth	Treatment*	200	75	30	3	Total Porosity	Total Plant	Grain
- m -		- - -	% greater	- - - - -		- % -	- - - %	- - -
0-0.2	0 T	7.3	13.0	16.5	19.8	45.4	100.0	100.0
	0 C	9.2	13.7	17.7	22.0	44.2	99.7	91.7
	0 N	13.0	17.9	21.1	22.2	50.1	79.8	71.5
	1 T	5.0	7.9	9.9	11.0	38.7	81.9	80.3
	1 C	7.9	15.7	19.9	21.1	40.9	87.8	92.2
	1 N	5.0	8.1	10.2	12.8	47.6	72.7	74.8
	2 T	4.6	8.8	11.4	14.0	39.4	72.6	84.5
	2 C	7.2	11.9	14.8	16.5	41.3	74.0	74.2
	2 N	11.0	14.1	17.1	21.1	49.4	79.8	80.9
0.2-0.4	0 T	8.3	13.9	17.1	19.0	40.5		
	0 C	9.9	14.6	19.2	24.6	40.5		
	0 N	9.6	13.9	16.8	18.8	46.8		
	1 T	6.1	9.5	11.8	14.0	37.2		
	1 C	7.6	15.4	20.0	22.7	38.7		
	1 N	6.3	9.0	10.8	13.8	45.0		
	2 T	5.6	9.0	11.6	14.1	36.1		
	2 C	6.8	10.5	13.5	17.0	35.3		
	2 N	9.3	12.2	15.8	19.3	44.2		
0.4-0.6	0 T	6.7	12.6	15.5	18.6	40.1		
	0 C	9.1	14.8	19.6	24.1	40.9		
	0 N	10.3	13.5	16.0	17.7	43.1		
	1 T	6.8	11.6	14.8	14.5	38.3		
	1 C	7.1	13.5	18.6	19.6	40.5		
	1 N	4.4	7.4	9.1	13.3	42.8		
	2 T	4.6	7.8	9.9	13.2	40.5		
	2 C	6.1	10.3	13.1	15.1	36.1		
	2 N	8.0	9.8	12.0	17.2	39.0		

*
0 = control; 1 = 10 t/axle; 2 = 18 t/axle
T = no subsoiling; c = soil conditioner; n = narrow-tined subsoiler

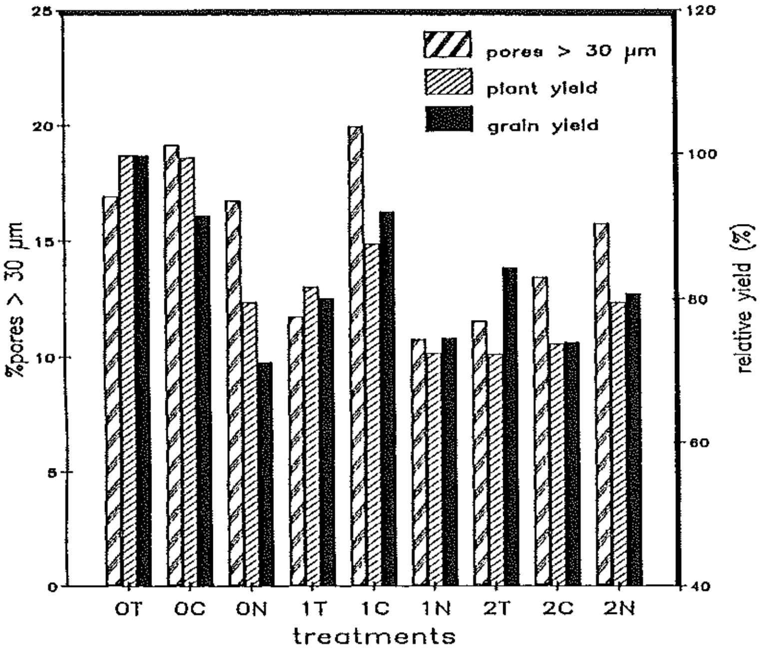

Figure 1. Pore sizes greater than 30 μm at depths between 0.2 and 0.4m and relative yields.

TABLE II. Correlation coefficients and levels of significance between pore size distribution, total porosity and crop yields.

		Pore Size (μm)				
Depth - m -	Yield	200	75	30	3	Total Porosity
0-0.2	Total	0.2418	0.3888	0.4604	0.5567	0.0443
	Plant	0.5308	0.3010	0.2123	0.1195	0.9099
0.2-0.4	Total	0.5876	0.7509	0.7493	0.7316	0.0265
	Plant	0.0961	0.0197	0.0201	0.0251	0.9462
0.4-0.6	Total	0.4668	0.7838	0.7835	0.8466	0.0819
	Plant	0.2052	0.0124	0.0125	0.0040	0.8340

CONCLUSIONS

On the basis of the above findings, the following conclusions can be drawn:

Heavy axle loading, soil conditioning and subsoiling had a significant effect in altering pore size distribution.

The effect of soil conditioning on improving pore size distributions decreased with increasing levels of compaction.

The benefits of subsoiling were limited to alleviating the effects of the 18 t/axle loading.

Pore size distribution is a better indicator of soil structure and crop response than is bulk density.

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FACTORS INFLUENCING SOIL STRENGTH INCREASES INDUCED BY COMPACTION

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ABSTRACT

Cultivated soils, subjected to compaction, often show marked increase of strength, which may be unfavourable for root penetration and may increase the amount of tillage required to produce acceptable seedbeds. Two determination techniques of tensile strength at different scales of soil organisation are used. The tensile strength of a small volume of soil, which organisation mainly results from particles packing, is shown to be highly correlated to clay content. Various factors leading to different friability of compacted clods are investigated, such as soil water content during compaction, compactness, and soil constitution (mineral and organic). The effect of drying, subsequent to compaction having occured at different water content, is emphasized.

INTRODUCTION

Soil strength and friability are very often proposed, when assessing the consequences of soil compaction on plant establishement, root developement, and yield (Trouse, 1971; Soane, 1985; Boone et al., 1987). Soil strength may affect root developpement, by directly influencing root penetration, or indirectly, by affecting the quality of tillage subsequent to compaction. Moreover, Tardieu et Manichon (1987) have shown that the spatial distribution of massive clods, in the ploughed layer, markedly influenced the root pattern of maize in deeper layers.

Several studies have been developed on clods and aggregates tensile strength (Rogowski and Kirkham, 1976; Braunack et al., 1979; Utomo and Dexter, 1981). The tensile strength has been shown to be dependent on the volume of the aggregates. But still the influence of the factors and conditions of compaction have little been investigated. In order to analyse soil strength, two levels of organisation will be taken into account.

MATERIALS AND METHODS

Experiments were done with various soils described in a previous paper (Guérif, 1988-a-b), presenting a wide range of clay contents, in order to investigate the influence of this particular factor.

Pore space organisation

Previous studies (Guérif 1988-c) have shown that pore space can be partitioned into intra-aggregates or textural pore space, which is due mainly to the packing state of the mineral particles, and inter-aggregates or structural pore space, which results from arrangement of structural elements (aggregates, crumbs) created by tillage and/or natural cracking. Textural pore space varies, for a given soil, with water content, and is not affected by under-wheel compaction.

Samples preparations

Soils were grinded, in an air-dried state, and sieved either between 2 and 3 mm or between 3 and 5 mm. A spherical shape was given to the bigger aggregates by mechanical abrasion. A mean diameter of 2 to 3mm was obtained. Those aggregates were dedicated to the determination of the textural tensile strength. When required, the aggregates were rewetted, under vacuum, up to zero water-matric potential. Drying to the required water content was carefully done under silica-gel, or to known matric potential in pressure plate extractors. The dried state was obtained under silicagel until no further loss occured, rather than in the oven. Oven-drying may induce microcracks. Compacted samples were obtained by uniaxial, confined compression, in a cylindrical mould. The required inter-aggregates (structural) void ratio was reached by compacting a calculated mass of 2-3 mm agregates into a given volume (diameter=7 cm, height=2.4cm), according to their intra-aggregates (textural) void ratio at the appropriate water content or water-matric potential. In order to estimate the feasibility of soils behaviour assessment from their constitution, samples of ten different soils, at three water-matric potential -100 hPa, -500 hPa, -1000 hPa, were compacted at a standard pressure of 100 kPa.

Determination of tensile strengthes

The tensile strengths of 60 spherical aggregates at each water content, and for each soil were determined by crushing the spheres between paralell plates (Rogowki, 1968; Dexter 1975; Dexter, and Kroesbergen, 1985; Guerif, 1988-a). The tensile strength ^{a}T was calculated for each aggregates using the equation :

(1)...................... $^{a}T = 0.576\, F/d$

where F is the force required to fracture the aggregate, and d is the distance between the two paralell plates.

The tensile strength of compacted samples, at each water content, at each structural void ratio, and for each soil, was measured, using the brazilian test, as described for soils by Kirkham, et al., (1959). The tensile strength ^{s}T was calculated for each cylinder using the equation :

(2)..................... $^{s}T = 2\, F / \; d\, h$

where d is the diameter and h the height of the cylindrical compacted sample. At each water content and each structural void ratio, two samples were made, one of wich was dried, in controled conditions, under silicagel, until no further weight loss occured. The tensile strength was both determined, at the water content at which the sample was compacted ($^{s}T_{w}$), and after drying ($^{s}T_{0}$).

For the aggregates, and for the compacted samples, the failure was tensile within a wide range of water content, and the flatening due to plastic deformation was negligible according to Frydman (1964) criterion. This agrees with Dexter's observations on agregates.

RESULTS AND DISCUSSION

Textural tensile strength (2-3 mm aggregates)

The mean textural tensile strengths of soils, determined in dry conditions, were shown to be highly correlated to the clay contents. A linear statistical relationship can be established :

(3)..................$aT_0 = a \, . \, CLAY + b$

where $^aT_0$ is the the mean tensile strength of spherical aggregates of 2-3 mm, and CLAY is the clay content. The effect of organic matter on the mean tensile strength did not appear to be significant in a multivariate linear regression. But Guérif (1988-b) showed that slight, but significant, effects of organic matters can be observed in samples of the same soil, but having different O.M. contents.

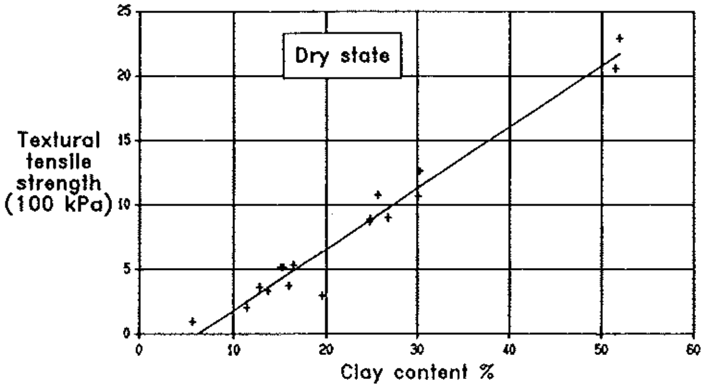

Fig.1 Influence of clay content on $^aT_0$.

The mean textural tensile strength of a soil, at a given water content, ^aT_w, was fairly well predicted by an exponential relationship such as :

(4).........$^aT_w = {}^aT_0 \, . \, \exp^{-k.((W - Ws) / CLAY)}$

where W is the water content of the sample, W_s is the residual water content after drying, under silicagel, until no water loss occurs, and k is an adjustment parameter.

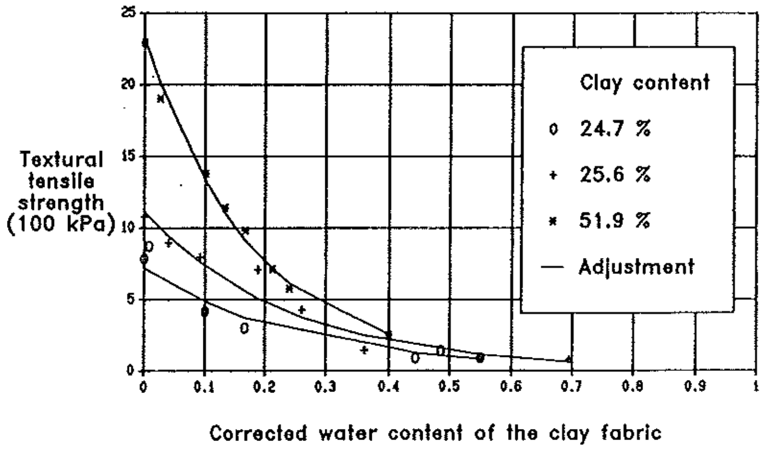

Fig.2 Influence of the moisture content of the clay on ^aT_w

Refering the water content to the clay content, allows to compare different soils (Fig.2). The ratio W/CLAY can be interpreted as the water content of the clay fabric. It seems that the tensile strength can be directly related to the consistency of the clay. It appeared that the limit, between fragile and ductile behaviours, occured for a given moisture content of the clay fabric, or better for a given water-matric potential in the conditions of the crushing test.

Tensile strength of compacted samples

Two components of the physical state were investigated, on the same soil (CLAY = 51.9%), the structural void ratio (e_s), and the water content W during compaction. The tensile strengths of the cylindrical artificial clods were both determined at the moisture content of compaction : ${}^{S}T_{W}$, and after drying : ${}^{S}T_{O}$.

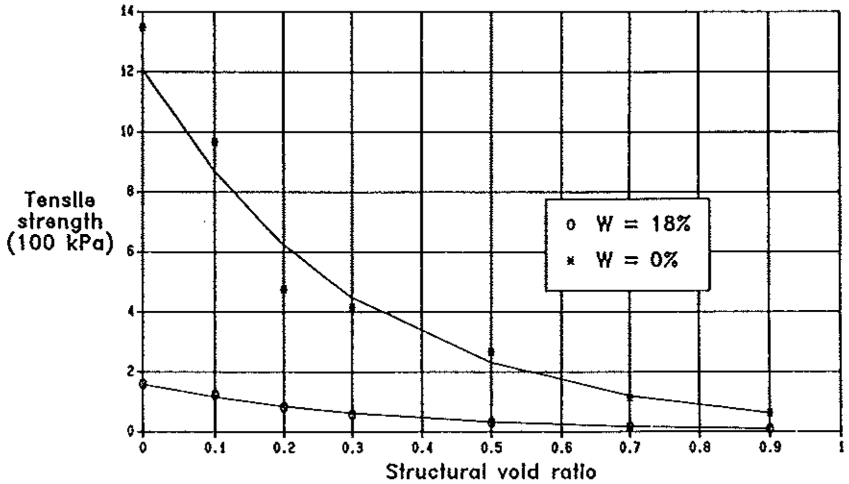

Fig.3 Influence of the structural void ratio (e_s) on ${}^{S}T$

At a given water content of compaction (W = 18 %), the tensile strengths decreased exponentially when the structural void ratio increased (Fig.3). The values of ${}^{S}T_{W}$ and ${}^{S}T_{O}$, for e_s = 0, did not reached the textural tensile strength at the corresponding water contents.

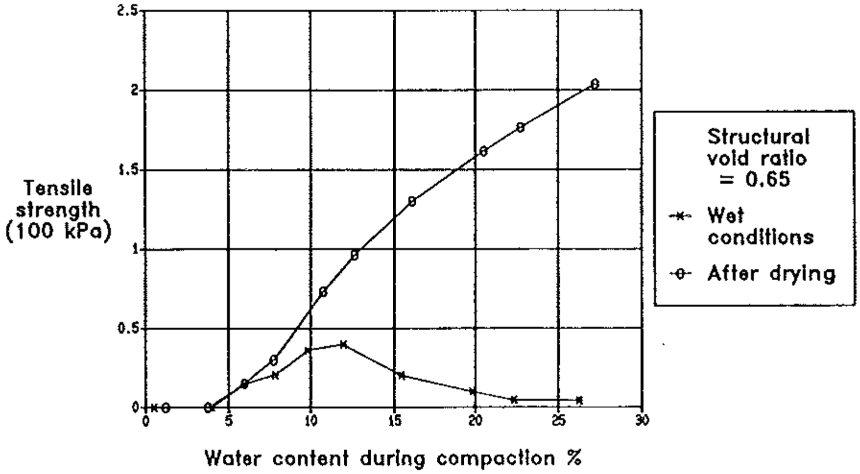

Fig.4 Influence of the water content during compaction on ${}^{S}T$

At a given structural void ratio (e_s = 0.65), ${}^{S}T_{W}$ varied according to the ability of aggregates to stick to each other when compressed, and according to their own tensile strengths $^{a}T_w$ (Fig.4). The first phenomenon was dominant in the range of $W < 10\text{-}12$ %, where $^{a}T_w$ was still very high compared with the srength due to the bondings between sticked aggregates. When $W > 12\%$ the orders of magnitude of the bondings inter and intra aggregates were similar. Drying the samples increased, of course, their tensile strengths. Moreover the higher was the initial water content during compaction, the higher was the resulting tensile strength $^{s}T_0$. Because the values of e_s were nearly unchanged after drying, an increase of compactness cannot explain this phenomenon. Both the quality of the bondings, and the contact area, between sticked aggregates, may have been modified. This phenomenon appeared to be lessened by organic matter content, and at the contrary, enhanced by Natrium.

Effect of soil constitution

The tensile srengths ($^{s}T_0$) of artificial clods, determined subsequently to drying, for different soils, were found to be dependent on clay content (Fig.5).

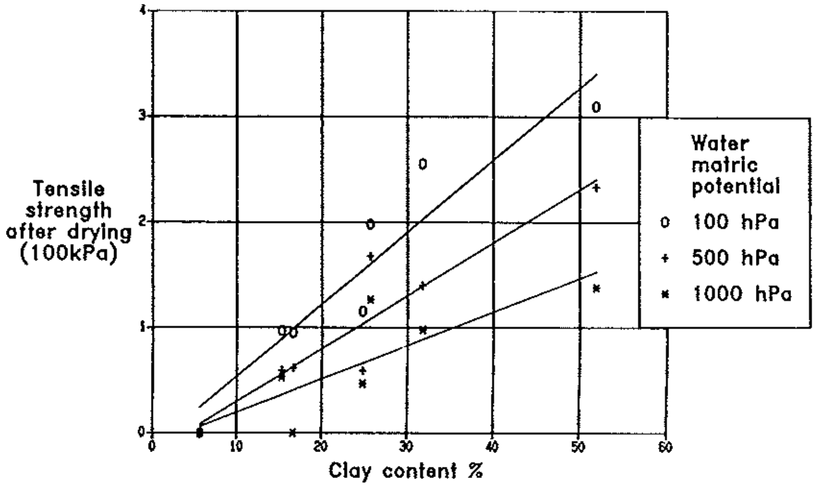

Fig.5 Influence of clay content on $^{s}T_0$, after a standard compaction of 100 kPa.

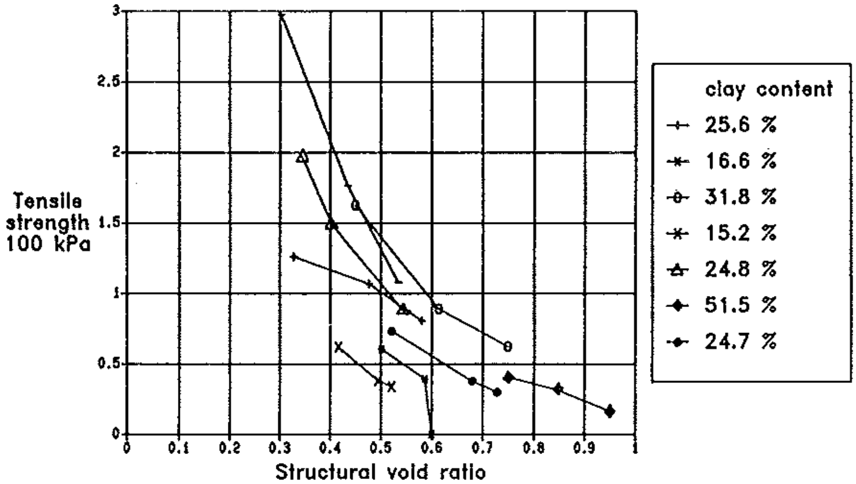

Fig.6 Influence of the structural void ratio(e_s) on $^{s}T_0$.

Being subjected to a standard compaction at 100 kPa pressure, their structural void ratio were not equal, but were dependent on clay content. $^{s}T_0$ depended on both the structural void ratio, e_s, (Fig.6) and the quality of the inter-aggregates bondings, which was influenced by clay content. Moreover, as demonstrated before with one soil, the wetter were the soils during compaction, the higher were their tensile strengths.

CONCLUSIONS

(1) The distinction between textural tensile strength, and structural tensile strength, allowed to analyse soil strength in heterogeneous soils.

(2) The tensile strength, defined at a textural level, and in dry condition, ${}^{a}T_{o}$, was found to be highly correlated to clay content. A statistical model has been elaborated to predict textural tensile strength at various moisture content, ${}^{a}T_{w}$.

(3) Such concepts can be introduced in models dedicated to compaction of aggregates beds, or used as a reference to appreciate the strength of structural elements.

(4) Those results will allow to assess the consequences of soil compaction, and participate in an estimation of soil "workability".

ACKNOWLEDGEMENTS

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INFLUENCE OF HIGH AXLE LOADS ON SUBSOIL PHYSICAL PROPERTIES AND CROP YIELDS IN THE PACIFIC NORTHWEST, USA

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ABSTRACT

A field experiment was initiated in the spring 1986 near Moscow, Idaho, USA, on a silt loam soil to determine the effect of high axle loads on subsoil compaction and crop production. Compaction treatments consisted of axle loads of < 5 (check), 10, and 20 Mg. Subsoil bulk density and impedance were increased by both high axle loads to a depth of 0.75 m. Spring pea and barley yields were not significantly reduced by the 10 Mg axle load treatment. Both crops suffered significant yield reductions from the 20 Mg axle load treatment. Compaction resulting from the 20 Mg load limited root growth reducing subsoil water extraction.

INTRODUCTION

Cultural practices for winter wheat production in the Pacific Northwest USA include rotations with spring crops in areas of adequate annual precipitation. Conventionally grown spring crops utilize numerous field operations resulting in heavy wheel traffic during wet soil conditions. The current trend toward heavier equipment, combined with field operations during undesirable soil moisture conditions, greatly increases the potential for serious soil compaction in the region.

The magnitude and depth of soil compaction is dependent on soil contact pressure and axle load (Sohne, 1958). Moderate axle loads > 8 Mg have been shown to increase vertical strain and produce inelastic failure at depths exceeding 0.5 m (Danfors, 1974). Voorhees et al. (1986) reported substantial subsoil compaction at depths > 0.3 m for axle loads > 4.5 Mg associated with spring field operations. Subsoil compaction from high axle loads was observed to persist for long periods, despite natural alleviating processes (Eriksson et al., 1974; Voorhees et al., 1986). Voorhees and Lindstrom (1983) and Eriksson et al. (1974) reported decreased crop yields as a result of subsoil compaction.

Axle loads of wheel tractors and other equipment used in the Pacific Northwest normally exceed 9 Mg. Therefore, research was conducted to determine the effect of high axle loads on crop production. The objectives of the study were (1) to determine the influence of high axle loads on subsoil physical properties, and (2) to investigate the impact of subsoil compaction on crop growth and yield.

METHODS

A field experiment was initiated in the spring 1986 near Moscow, Idaho, USA, on a Palouse silt loam (fine-silty, mixed, mesic Pachic Ultic Haploxeroll). The site had been in grass pasture since 1972 and had not received any previous axle load traffic exceeding 5 Mg. The statistical design was a randomized split plot, with axle load main plot treatments and crop split plot treatments. The axle load treatments were < 5 (check), 10, and 20 Mg. The high axle load treatments were applied track-to-track a total of four times over the entire plot surface at experiment initiation. The soil water content at the time of compaction was near field capacity. Each plot was 9 m by 7.5 m. Each treatment was replicated four times.

After application of the axle load treatments, the entire plot area was plowed to a depth of 0.2 m to alleviate surface compaction. Prior to planting crops, the plots were disked and harrowed for seedbed preparation following conventional tillage practices for the region. Two crop rotations were utilized (1) winter wheat (Triticum aestivum L.)-spring barley (Hordeum vulgare)-spring pea (Pisum sativum), and (2) winter wheat-fallow-winter rape (Brassica Napus). Plots were harvested at crop maturity using a small combine.

Several soil parameters were measured to determine the depth and magnitude of subsoil compaction. Bulk density was determined at 0.15 m increments to 0.9 m using a volume core (5 cm diam by 3 cm) method. Soil impedance was measured at 0.05 m increments to the 0.8 m depth using a constant rate cone penetrometer. Saturated hydraulic conductivity was determined at depths of 0.15, 0.30, 0.45, and 0.60 m using a constant head permeameter. Three measurements per depth per treatment per rep were taken for each parameter. Soil water content was measured in each plot using a neutron moisture probe. Measurements were taken in 0.15 m increments to the 1.5 m depth at two week intervals through crop maturity.

RESULTS

Bulk density and soil impedance were measured immediately after high axle load treatments were applied. Bulk density as a function of depth and axle load is shown in Figure 1. Subsoil bulk densities were influenced to the 0.75 m depth by both high axle load treatments. Bulk density at the 0.3 m depth was increased 0.11 Mg m^{-3} by the 10 Mg axle load and 0.38 Mg m^{-3} by the 20 Mg axle load compared to the 5 Mg axle load treatment. Subsoil impedance values (Fig. 2) were influenced similarly as bulk density by both high axle load treatments. Maximum soil impedance (1.3 MPa) resulting from the 20 Mg axle load occurred within the 0.2 to 0.3 m depth increment. Soil impedance was increased at all depths by approximately the same magnitude under the 10 Mg axle load.

Saturated hydraulic conductivity (SHC) as a function of depth and axle load treatment is given in Table I. The SHC

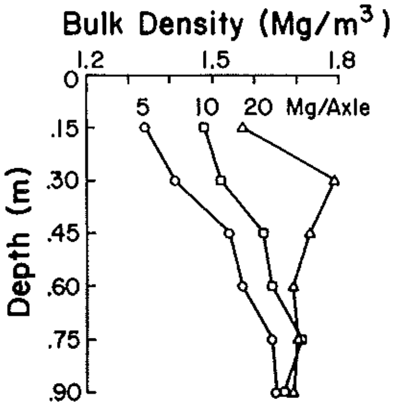

Fig. 1. Variation of bulk density with depth immediately after axle load treatments.

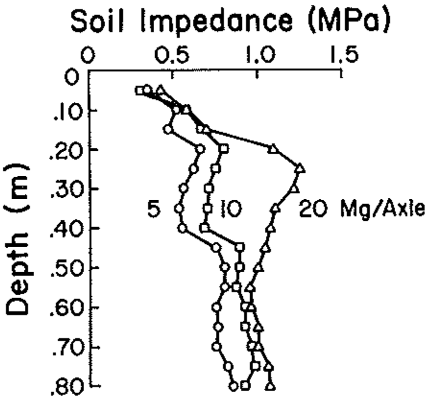

Fig. 2. Variation of soil impedance with depth immediately after axle load treatments.

was significantly reduced only at the 0.3 m depth as a result of the 10 Mg axle load. Values of SHC were significantly decreased at the 0.3 and 0.45 m depths from the 20 Mg axle load compaction treatment. While not significant, SHC was substantially reduced at the 0.6 m depth as a result of the 20 Mg axle load treatment.

Soil water extraction by spring barley (Fig. 3) and by spring peas (Fig. 4) was not seriously affected by soil conditions resulting from the 10 Mg axle load in 1986. Both crops suffered substantial reductions in depth and amount of subsoil water extraction due to compaction resulting from the 20 Mg axle load treatment.

Yields of spring barley and spring peas (Table II) were similarly affected by high axle loads in 1986. Reduction in yield of either crop was not significant as a result of the 10 Mg axle load treatment. Crop yields were significantly

TABLE I

Effect of axle load treatments on field saturated hydraulic conductivity (cm hr^{-1}) at several depths in 1987

	Axle load (Mg)			
Depth (m)	5	10	20	$LSD_{0.05}$
0.15	3.8	5.7	2.9	2.5
0.30	7.1	3.6	1.3	2.5
0.45	3.5	3.8	0.6	1.1
0.60	4.0	3.2	1.1	3.2
$LSD_{0.05}$	2.9	2.7	1.1	

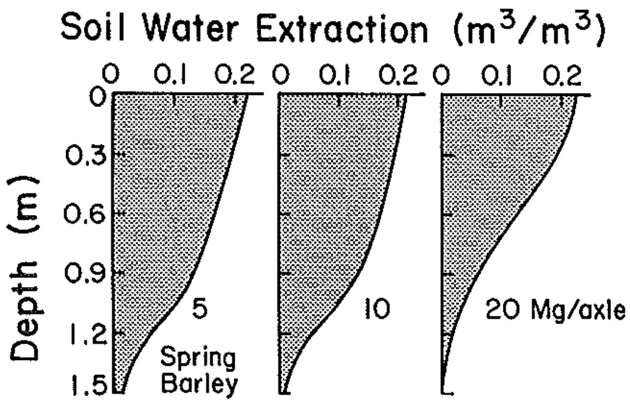

Fig. 3. Influence of axle load treatments on subsoil water extraction by spring barley in 1986.

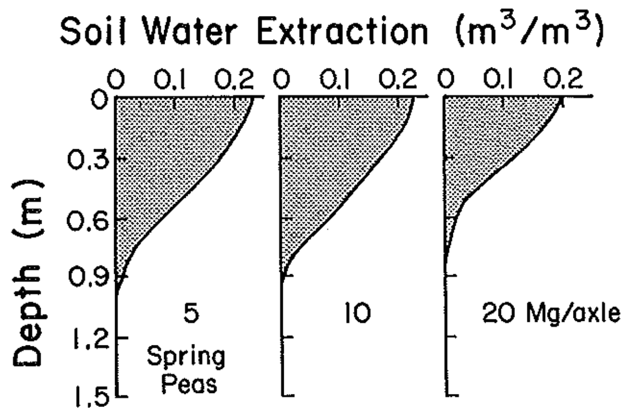

Fig. 4. Influence of axle load treatments on subsoil water extraction by spring peas in 1986.

TABLE II

Effect of axle load treatments on crop yields (kg ha^{-1})

Axle Load (Mg)	Spring barley		Spring peas	
	1986	1987	1986	1987
5	5193	5550	1979	1999
10	4724	5353	1936	2100
20	3578	4314	1430	2341
$LSD_{0.05}$	1374	918	222	711

reduced (approximately 30%) as a result of the 20 Mg axle load treatment. In 1987, no reduction in yield of spring peas as a result of axle load occurred. Spring barley yield reductions while somewhat less in 1987 were similar to yield reductions in 1986. Winter wheat and winter rape yields (not shown) were not influenced by high axle load treatment in 1987. Precipitation during June and July was about 40 mm greater during both months in 1987 than in 1986, alleviating possible crop stress due to low soil water extraction resulting from subsoil compaction.

DISCUSSION

Subsoil physical properties were not greatly influenced by the 10 Mg axle load treatment, which is approximately the axle load of wheel tractors used in the Pacific Northwest. Bulk density, soil impedance, and saturated conductivity below the tillage zone were substantially impacted by the 20 Mg axle load, similar to finding of others (Eriksson et al., 1974; Voorhees et al., 1983). However, subsoil compaction as a result of both high axle load treatments might have possibly been greater at another site. The organic matter contents of the upper 0.15 m surface layer and the 0.15 to 0.3 m soil layer were 3.6 and 1.9 percent as a result of time under pasture. Normal levels of organic matter in the surface zone of agricultural soils are approximately 2 percent. The higher organic matter content at this site could have produced better soil structure stability, and hence, made the soil more "forgiving" to high axle loads than other agricultural soils.

Levels of subsoil impedance resulting from the 20 Mg axle load were below critical root restriction values (Taylor et al., 1966). However, the increased soil strength below the tillage zone limited root growth and greatly decreased crop subsoil water extraction causing a significant yield reduction in 1986. The occurrence of substantial precipitation in 1987 decreased dependence on subsoil water extraction by all crops except late-maturing spring barley.

CONCLUSIONS

(1) Axle loads of 10 and 20 Mg increase bulk density and soil impedance to depths considerably below depth of primary tillage.

(2) Axle loads of 20 Mg increase subsoil impedance reducing root growth. Decreased root growth limits subsoil water extraction and reduces crop yields under dryland conditions.

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EFFECTS OF SOIL STRUCTURE AND STRESS DURATION ON PRESSURE TRANSMISSION IN TILLED SOILS

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ABSTRACT

Pressure transmission in structured soils can not be calculated in the same way than in homogeneous, non aggregated soils, by texture dependent values for the concentration factor according to Fröhlich (1934). In order to determine the compression behaviour of structured soils, pressure transmission measurements have to be performed, and structure dependent values for the concentration factors have to be determined. The results demonstrate, that concentration factors in aggregated soils are dependent of aggregate properties, preconsolidation load values of the different soil horizons and soil hydraulic properties. Thus, compaction is influenced by stress duration.

INTRODUCTION

The transmission of total stresses as effective stresses on the solid phase of the soil is a time dependent process, because the decrease of pore water pressure is a function of the hydraulic conductivity of the soil. In the soil mechanical literature much information is given about the pressure transmission and compression behaviour of homogeneous, saturated soils (e.g. Terzaghi 1925, Fröhlich 1934).

But in unsaturated, different structured and different textured agricultural soils, there is a great variability of soil hydraulic properties, because neither pore size distribution nor pore continuity are constant. Consequently, this results in a different pressure transmission and time dependent settlement behaviour. Horn et al. (1987) described, that the speed of wheeling and the number of passes cause different degrees of compaction. But there is a lack of information about the processes in detail, that occur during loading in structured soils.

Therefore, soil compaction and pressure transmission measurements with static loading have been performed under laboratory conditions, to determine the influence of pore system, it is the inter- and intra- aggregate pore system, in different structured soils.

MATERIAL AND METHODS

The experiments were carried out at undisturbed soil samples of different structured, typical bavarian agricultural soils. The soil physical characteristics are given in table I. In the following, only the numbers of the sites according to table I are mentioned.

Table I: Soil physical characterization of the sites

site	hor.	depth (cm)	structure	dB (g/cc)	texture T (%)	U	S	K_f (cm/sec)	Pv (kPa)
1	Ap	10-14	sub	1,51	15	82	3	$3{,}6 \times 10^{-6}$	n.r.
	Ap	20-24	pol	1,50	9	86	5	$2{,}1 \times 10^{-5}$	n.r.
	Al	30-34	koh	1,43	16	80	4	$5{,}7 \times 10^{-5}$	n.r.
	Bt	45-49	pol	1,44	29	68	3	$1{,}3 \times 10^{-4}$	n.r.
2	Ap	10-14	Ek	1,41	6	9	85	$1{,}6 \times 10^{-3}$	60
	Ap	24-28	Ek	1,55	9	7	84	$9{,}1 \times 10^{-4}$	80
	Bv	30-34	Ek	1,62	6	9	85	$4{,}6 \times 10^{-4}$	170
	Bv	50-54	Ek	1,49	9	10	81	$8{,}3 \times 10^{-4}$	80
3	Ap	6-10	sub	1,42	6	22	72	$3{,}6 \times 10^{-3}$	9
	Ap	24-28	pol	1,53	11	18	71	$2{,}5 \times 10^{-3}$	26
	Bv	30-34	pol	1,69	11	24	65	$4{,}9 \times 10^{-4}$	205
	Bv	40-44	Ek	1,69	13	24	63	$2{,}0 \times 10^{-3}$	130
4	Ap	2- 6	sub	1,36	31	43	26	$4{,}8 \times 10^{-4}$	10
	Ap	12-16	pol	1,43	30	43	27	$9{,}3 \times 10^{-6}$	22
	BvCv	25-29	pol	1,59	42	36	22	$1{,}2 \times 10^{-7}$	115
	BvCv	40-44	pri	1,44	45	38	17	$3{,}5 \times 10^{-6}$	105

It is: dB=bulk density, K_f=saturated hydraulic conductivity, Pv=preconsolidation load at a water tention of 60 hPa, T=clay, U=silt, S=sand, Ek=single grain structure, 1) Orthic Luvisol, 2) Sandy Cambisol, 3) Loamy Sandy Cambisol, 4) Calcereous Phaeozem

Pressure transmission measurements in the laboratory were carried out at undisturbed soil monoliths (60x40x30 cm) of the topsoil (0-30 cm) and of the subsoil (16-46 cm). After saturation and redrying to 60 hPa, the monoliths were loaded statically with a load range of 25 to 250 kPa. The circular load transmitting contact area had a diameter of 10 cm. Stresses in different depths (8, 12, 16, 20 cm in each monolith) were registrated by strain gauges, which had been installed according to the scheme in fig. 1. More detailed information about the method is given by Horn (1980).

According to the formula of Newmark (1942), concentration

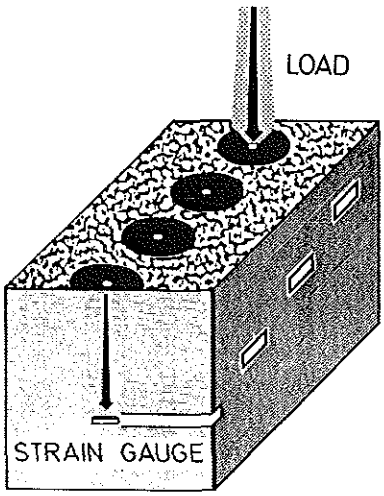

Fig. 1: Installation scheme of the strain gauges in the soil monoliths (60x40x30cm)

factors were calculated out of the measured stress values.

The load and time dependent settlement of the undisturbed and predried soil samples (240 ccm) was done by the confined compression test, with a load range of 10 to 800 kPa.

Preconsolidation load values of the soil horizons were determined by the method of Casagrande (1936).

The values of the air permeability were measured according to Kmoch and Hanus(1965), while all the other soil physical properties were determined according to Hartge (1971).

RESULTS AND DISCUSSION

The spatial pressure transmission, it is the form of the equipotential lines, is described by the concentration factor V_k, according to Newmark. As to be seen in fig. 2 and fig. 3, this factor is not a constant value down the profile, but is effected by soil structure, load intensity and duration of loading.

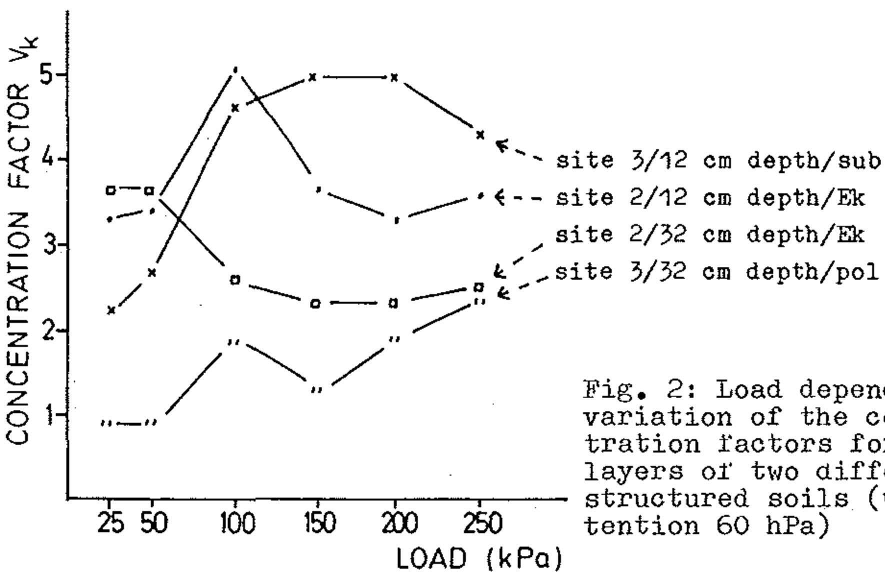

Fig. 2: Load dependent variation of the concentration factors for two layers of two different structured soils (water tention 60 hPa)

In fig. 2, the effect of preloading on the value of the concentration factor is shown for two layers of two different structured soils. It is to be seen, that concentration factors are smaller in the higher precompacted plow-pan layer in 32 cm depth, while they are higher in the topsoil, at each of the sites. Thus, stresses at the soil surface are transmitted deeper, but closer to the perpendicular line in topsoil, compared with the stresses in the plow-pan layer, which are distributed more horizontally. Additionally, smaller loads applied to the surface, were stronger reduced with increasing depth at the aggregated site, due to the higher strength of the aggregates. However the loads exceed aggregate strength, that correnponds to the preconsolidation load value (Lebert et al. 1987), then aggregates get crushed and the pressure transmission behaviour is mainly effected by texture properties. Consequently, the concentration factors reach similar values at the both sandy soils.

In fig. 3, the effect of stress duration on pressure transmission is shown. At constant load, the values of the concentration factors increase with increasing time of loading. The reason for that is given by the effective stress equation of Terzaghi, at which the proportion of the neutral stresses on total stresses decrease, depending on the hydraulic conductivity. Therefore, pressures will be transmitted deeper down the profile and, at the same depth, stresses increase with increasing time.

Consequently, short time loading results in higher soil strength. Soil strength however, is characterized by the value of preconsolidation load. In fig. 4, the time dependent alteration of the preconsolidation load values is shown for a clayey profile, with low hydraulic conductivity. Preconsolidation load Pv is higher and compaction is smaller at a short time loading of 30 secs, than at a long time loading of 23 hrs.

In fig. 5, the consequences of these soil mechanical processes on soil physical properties are demonstrated by the value of the air permeability. The air permeability gives an in-

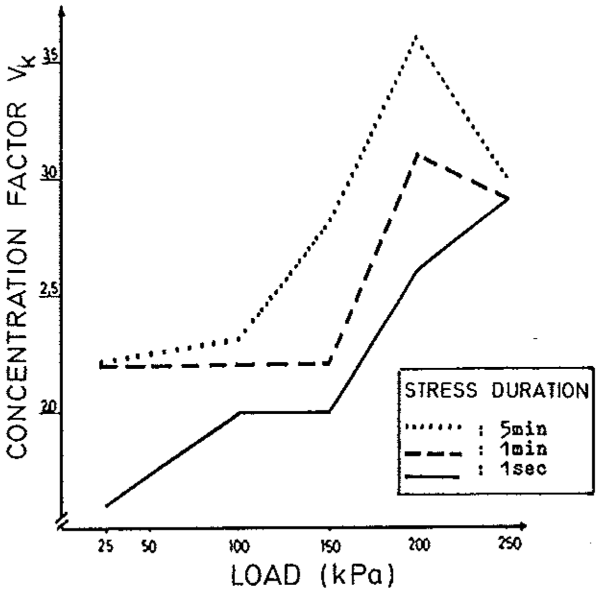

Fig. 3: Load dependent variation of the concentration factors at different stress duration (site 1, depth 12 cm, water tention 60 hPa)

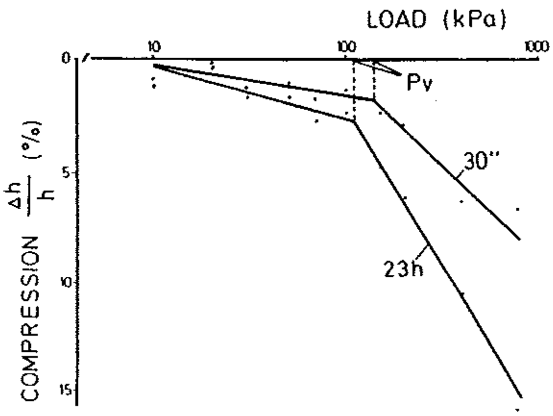

Fig. 4: Effect of stress duration (30 secs and 23 hrs) on the compression behaviour and the preconsolidation load Pv of a clayey soil (site 4, depth 25-29 cm, water tention 300 hPa)

formation about pore diameter and pore continuity and about the changement of soil structure after loading.

At a load of 20 kPa, it is a value below preconsolidation load (see table I), no change of the air permeability is to be seen. Thus, soil structure remains stable, pore system and its continuity don't get reduced, independent of stress duration. If, however, the soil is loaded with intensities of 100 and 200 kPa, that exceed preconsolidation load, plastic deformation dominates the settlement of the soil and pore diameter and pore continuity get more and more reduced, dependent of stress duration.

It is obvious, that the load dependent differences of the pore size distribution are highly effected by the duration of loading. Short time loading results in minor changes of soil structure, compared with the long lasting compaction. Therefore, load bearing capacity is strongly increased at a short time of loading.

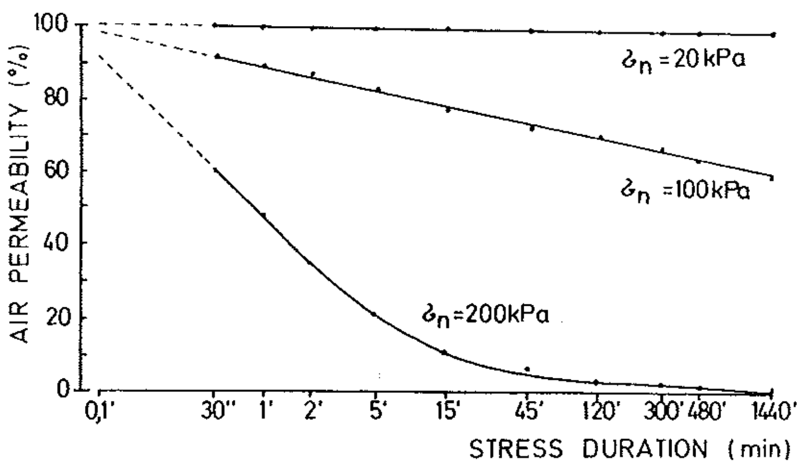

Fig. 5: Effect of stress duration on the reduction of the air permeability at different load intensities δn (unloaded = 100 %, site 4, depth 12-16 cm, water tention 60 hPa)

CONCLUSIONS

1) Preconsolidation load values increase and concentration factors get smaller with decreasing stress duration.

2) Thus, fast wheeling protects soil structure from compaction, especially in soils with low hydraulic conductivity.

If dynamic forces dominate at the wheel/soil interface or within the soil, shearing results in an additional destruction of structure elements, especially under wet conditions. Then the influence of soil structure on soil strength is reduced and soil texture properties get more improtant.

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WHEEL FACTORS INFLUENCING SOIL BREAKAGE IN VARIOUS SOIL CONDITIONS

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ABSTRACT

In the operation of a tractor, its wheels can cause soil compaction. However, the wedge-lugged wheels of a boat-type tractor dig holes in the soil and break or loosen the soil around the holes. This is because broken faces appear along the tracks of the tip of the wheel blade and soil is forced out of the hole thus made. Experiments showed that soil breakage went up by 5% to 10% with the replacement of an ordinary rubber type wheel by a wedge-lugged wheel. A higher degree of breakage is of course advantageous to the growth of crops.

Wedge-lugged wheels created more and longer cracks and more and higher peaks in loam soil than in clay. In other words, the degree of breakage was higher in loam soil.

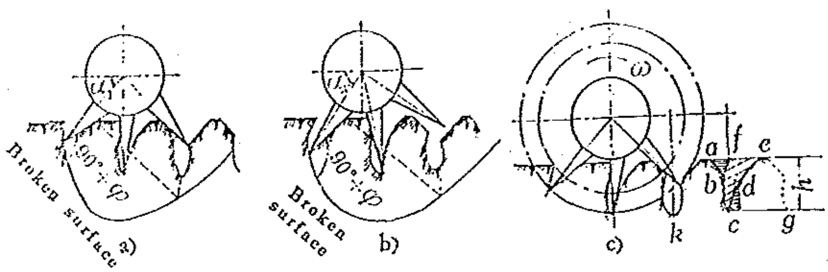
INTRODUCTION

It is well known that the rubber wheels of a conventional tractor can cause soil compaction. This effect influences firstly the growth of crops and secondly, it increases the specific resistance in the areas covered by the rubber wheel compared with that in the other areas. As a result there is an increase in the total cutting resistance, when a rotary cultivator is working behind the tractor, thus reducing the degree of soil breakage in the area covered by the rubber wheels.

In contrast the wedge-lugged wheels of a boat-type tractor exercise the opposite effect by digging holes in the soil and breaking or loosening the soil round the holes.

How do the wedge-lugged wheels of the boat-type tractor break up the soil? It is because while the wheels are moving, the blades on it first pierce into and then move out of the soil in sequence, producing rows of holes behind, which synchronize with the orbital motion of the blades, as in Fig. 1(c). The holes vary in shape and size, with the depth of piercing, geometric parameters and rate of slipping of the driving wheels.

The motion of the blade is a combination of horizontal and vertical movement, during which the driving surface of a blade cuts and presses the soil continuously both horizontally and vertically, in section fbac Fig. 1(c). where the blade tip touches the soil and then moves to the bottom of the hole, the blade cuts and presses the soil downwards and backwards. According to Rankine's theory of soil compression, a broken face will appear along the movement of the blade tip. The face is represented by a logarithmic helix. Fig. 1(a). shows the broken face made by the blade tip at an angle of α_1, and Fig. 1(b) shows the broken face made at an angle of α_X. The broken face numbering X can loosen the soil.



(a) Broken surface made at an angle of α_1 (b) Broken surface made at an angle of α_x (c) Moving track and hole formation

Fig. 1. Details of hole formation

In Fig. 1(c) section **cd**, at which the blade tip moves from the bottom of the hole to its opening, the tip cuts and presses the soil backwards and upwards, from y broken faces while bringing damage to the soil in the section cdege, while leaving the hole, the upper front part of the blade may cut and press the soil in section **fabf**, forming Z broken face, bringing damage to the soil in section **abcka**. On the above analysis, we might conclude that in the operation, a wedge-lugged wheel will break up the soil in the front and back of the hole.

EXPERIMENTAL TESTS

One comparative experiment was made using wedge-lugged wheels and rubber wheels separately in the dry field at Zhejiang Agricultural University. The relationship between pressure, sinkage and the content of water in the tested soil is shown in Fig. 2. The blade digs holes in the area covered by the wedge-lugged wheel, so the soil round the holes is broken up, and creates a lot of cracks and a small protrusion. It shows that not only are the holes formed in the area covered by wedge-lugged wheels but also the soil round the holes is cracked. This can make the soil easier to break up, and reduce the specific resistance.

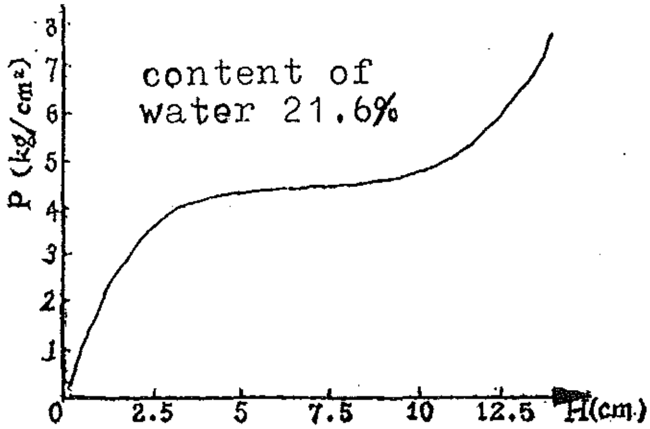


Fig. 2. The pressure-sinkage relationship in loam soil.

The pressure from the wedge-blade creates cracks and protrusions in the soil round the hole. Measurements showed that 80% of holes have cracks in such soil. Generally the cracks are 50 mm - 100 mm long. The largest one may be up to 150 mm long (Fig. 3). This shows that the picking of the blades can do good not only to the soil breakage round the holes, but also to the soil near the holes. This contrasts with the situation following the use of rubber wheels when the soil will be compated and there will be no cracks.

Fig. 3. The hole and cracks around it in loam soil.

The experiment made with rubber wheels and wedge-lugged wheels gave the following results for the soil-breaking performance of boat-type tractors at various sites.

Table 1. Soil -breaking performance with various driving wheels

Wheel type	Lump size distribution, % by weight		
	< 4 cm	4-8 cm	> 8 cm
rubber wheel	74.65%	13.20%	12.15%
wedge-lugged wheel	77.40%	11.65%	10.95%

The data in Table 1 show that the weight of small lumps went up by 5% to 10% with the replacement of rubber wheels by wedge-lugged wheels in the area covered by the wheel. That is to say wedge-lugged wheels can cause cracking of the soil in the area covered by wedge-lugged wheels, thus improving the soil-breaking performance of the rotary cultivator and better growth of crops.

The experiment proved that wedge-lugged wheels can break up the soil near the holes and reduce the specific-resistance of the soil in the area covered by the wedge-lugged wheels (in such conditions, the specific resistance will decrease about 50%), thus cutting down the total resistance to the following implements.

The experiment with rubber wheels and wedge-lugged wheels was carried out in clay soil in the wheat field in Kiasan County, Zhejiang province. The pressure-sinkage relationship and content of water is shown in Fig. 4.

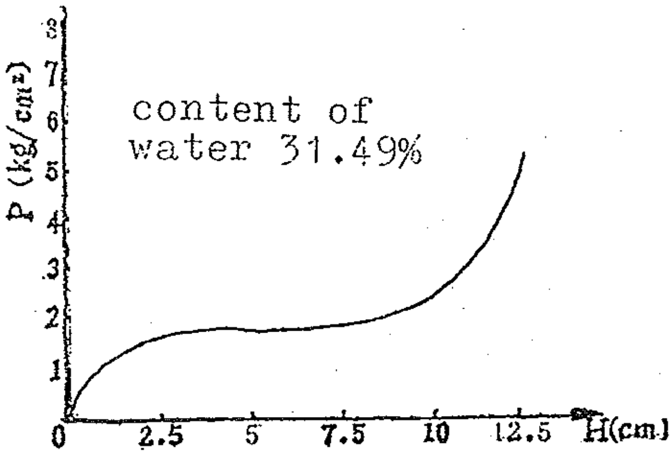


Fig. 4. The pressure-sinkage relationship in clay soil

The experiment showed that the cracks round the holes decreased remarkably and their length also decreased in clay soil, and their height of protrusion dropped.

The experiment made in clay soil (Fig. 5) showed that the length and the number of cracks are both reduced, and that the height of protrusion dropped also. The determination showed that only 40% of the holes had cracks, and that their length ranged between 20 mm and 50 mm, with the largest cracks being 70 mm long. The break-up of the soil was reduced and therefore the following cultivator breaks the soil into bigger clods.

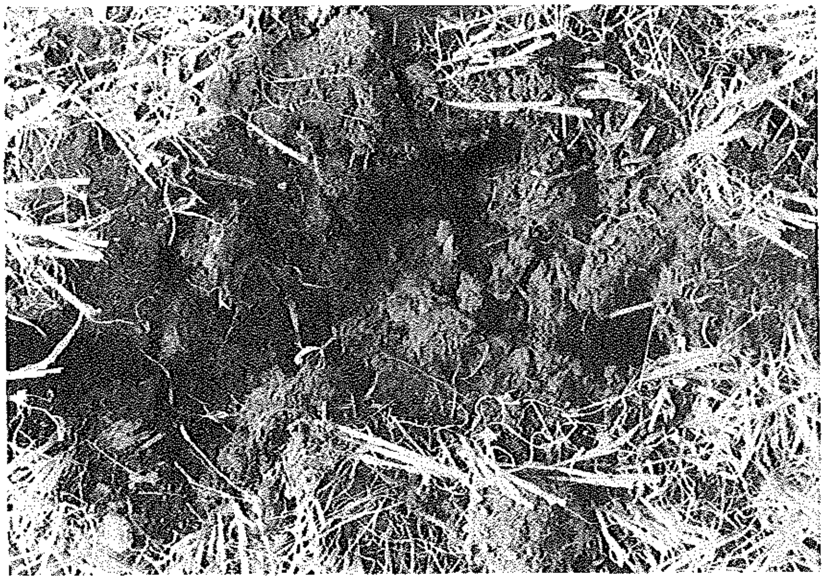


Fig. 5. The hole and the cracks around it in the clay soil

CONCLUSIONS

This paper is concerned with the wheel factors influencing soil breakage in various soil conditions. The major conclusions of this paper are:

(1) In contrast to the action of a rubber wheel causing soil compaction, the wedge-lugged wheel of a boat-type tractor digs holes in the soil and creates cracks and peaks in front and behind the holes in the soil that have been made by the blades. Such soil is easy to break in the following rotary cultivation.

(2) The experiments showed that soil breakage went up by 5% to 10% on an average with the replacement of the rubber wheels by the wedge-lugged wheels. A higher rate of breakage is of great advantage to the growth of crops.

(3) Experiments made in various soil conditions showed that wedge-lugged wheels create more and longer cracks in loam soil than in clay soil. In other words the damage to loam soil made by the blade tip is greater than that to clay soil.

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EFFECTS AND DURATION OF COMPACTION ON SOIL AND PLANT GROWTH

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ABSTRACT

A silty clay and a silt loam soil were compacted by heavy farm equipment. Penetration resistance measurements showed that this compaction existed in the subsoil and persisted for more than 4 years. Hydraulic conductivity of saturated soil cores decreased with increasing levels of compaction. Corn emergence rate was slowed during the first growing season after compaction, but plant population was not affected. Plant height was lower in the compacted plots in all years. Corn grain yields were reduced in the compaction treatments the first year after compaction at both sites and the second and fourth years at the silt loam site and silty clay site, respectively.

INTRODUCTION

Research on soil compaction over the past half century has been extensive--but most has been on genetic or tillage induced hardpans and surface soil compaction. Results published from these studies are numerous and many of them have been summarized by Barnes et al. (1971). However, until recently, subsoil compaction has received less attention (Hakansson et al., 1987).

Soehne (1958) calculated pressure distribution in a soil for different loads and tire sizes. He found that as the total load and tire size were increased, the maximum depth to which the compaction penetrated also increased. Thus, increasing the total weight and tire size of a machine will likely lead to subsoil compaction.

It is often assumed that natural forces such as wetting and drying cycles, and to a greater extent frost penetration to the subsoil, will alleviate compaction below the plow layer (McKibben, 1971). However, soil compaction by heavy farm equipment can cause lasting effects in the soil at depths below the tillage zone (Hakansson et al., 1987). Blake et al. (1976) found bulk density and penetrometer resistance were higher on compacted subsoil than in non-compacted subsoil after ten seasons of natural forces. Voorhees (1983) reported that natural forces had a limited effect on alleviating wheel-induced soil compaction in the plow layer of a clayey soil. Voorhees et al. (1986) indicated that subsoil compaction effects persisted after four seasons in Minnesota, U.S.A. Based on corn yield and soil bulk density, Gameda et al. (1987) noted that subsoil compactive effects were alleviated after three seasons of natural forces in Ontario, Canada.

The effects of subsoil compaction on crop yield and plant development have been studied. Wittsell and Hobbs (1965) found subsurface compaction had a more adverse effect on wheat yields than surface compaction. Gaultney et al. (1982) observed corn yield reductions of nearly 50% because of subsoil compaction in a relatively wet growing season. Gameda et al. (1985) found that subsoil compaction by heavy equipment on clay and loam soil caused yield reductions in corn.

This study was conducted to determine how long subsoil compaction would last and what effects it would have on crop growth in Wisconsin, U.S.A.

MATERIALS AND METHODS

This study was conducted from 1983 to 1986. The research plots were established in May 1983 at Lancaster and Valders, Wisconsin, U.S.A. on a silt loam and silty clay soil, respectively. Three levels of compaction were established at each location, a control (traffic kept <4.5 tonne, t), 8, and 12.5 t total axle load in randomized complete block design. The 8 t compaction was applied at both sites with a tractor. The 12.5 t compaction was applied with a combine and liquid manure spreader at the Lancaster and Valders sites, respectively. Each site had four blocks. The compaction was applied by completely covering the plot area with tracks from the aforementioned equipment.

The silt loam site was chisel plowed and disked after compaction and chisel plowed in the fall and disked in the spring prior to planting corn each year thereafter. Similarly the silty clay site was field cultivated after compaction and moldboard plowed in the fall and disked in the spring the following 3 years. Each site was planted to corn (*Zea mays* L.). Row spacings were 0.91 and 0.97 m at the silt loam and silty clay site, respectively.

Bulk density and hydraulic conductivity measurements were performed on soil core samples (7.6 cm diam. x 7.6 cm high) taken in the fall of 1983. These samples were taken at the soil surface in both sites and 15 and 53 cm at the silt loam site. In addition to the surface, samples were taken at 27, 54, and 73 cm depths at the silty clay site. Hydraulic conductivity determinations of saturated soil cores were made according to Klute (1965) and bulk density following procedures outlined by Blake (1965). Cone penetration resistance measurements were made with a constant rate penetrometer (Lowery, 1986). The cone had a base of 129 mm^2 (Am. Soc. Agric. Eng., 1983). Depth of cone penetration was to approximately 50 cm.

Corn emergence rates were monitored in 1983 and 1984. Plant height, with leaf extended, was measured each year. Grain yield was measured each year.

RESULTS AND DISCUSSION

Soil compaction by heavy farm equipment extended to the subsoil and persisted 3 years. Four months after the compac tion was applied, the upper 20 cm at each site and upper 40 cm of the silt loam site showed increased bulk density with increasing compaction. Cone penetration resistance also increased with increasing compaction (Tables I and II). For both soils, the compaction effect is significant to a depth of 24 cm. Tables III and IV show this compaction persisted until 1986. Compaction effects persisted from 16 to 46 cm in the silt loam soil and from 18 to 34 cm in the silty clay soil.

The hydraulic conductivity (K) of saturated soil cores (Fig. 1) taken 4 months after compaction gave varying results. The surface of each soil had decreasing K values with increasing compaction. This was not the case at lower depths, where no trends were found except at the 15-cm depth in the silt loam soil where the control was much greater than the others.

Plant emergence rates were taken the first and second year of the study. The time for 100% emergence was delayed 4 and 8 days for the 8 and 12.5 t compaction, respectively at the silt loam site. These data were not collected for the other site. Although the emergence was delayed, the population was not affected by compaction and the emergence was not affected the second year. Other plant growth parameters affected by compaction included plant height. Mature plant height was reduced by compaction the first and second year at both sites and the third at the silt loam (Table V). The most dramatic effects occurred the first year at both sites and the second and third year at the silt loam site, where the mature plant height was decreased with each increasing level of compaction. In most cases these differences were significant (Table V).

Corn yield was reduced with increasing levels of compaction the first and second year at the silt loam site and the first and last year at the silty clay site (Table VI). Reduced yield at the silty clay site the fourth year was unexpected and attributed to very wet soil conditions because this was a year with higher than normal rainfall. This suggests that the effect of prior compaction may reappear under certain weather conditions.

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TABLE I

Cone penetrometer index (kPa) for silt loam soil, 1983

Depth (cm)	Compaction level (tonne) <4.5	8.0	12.5
0-2	1240a*	2180b	1570ab
2-4	1420a	2750b	2500b
4-6	1590a	3130b	3400b
6-8	1740a	3190b	3930b
8-10	1720a	3260b	4080b
10-12	1780a	3210b	4410b
12-14	1820a	3160ab	4690b
14-16	1780a	2990ab	4930b
16-18	1850a	2720a	4860b
18-20	1920a	2900ab	4460b
20-22	2090a	3000ab	3821b
22-24	2230a	3050ab	3390b
24-26	2390	3050	3270
26-28	2610	3110	3280
28-30	2680	3140	3210
30-32	2890	3140	3290
32-34	3060	3360	3430
34-36	3270	3470	3500
36-38	3450	3460	3480

*Rows with the same letter or no letter are not significantly different at the 5% level.

TABLE II

Cone penetrometer index (kPa) for silty clay soil, 1983

Depth (cm)	Compaction level (tonne) <4.5	8.0	12.5
0-2	560	610	650
2-4	740	880	940
4-6	1210	1930	2320
6-8	1530a*	2870ab	4080b
8-10	1590a	3630b	5130c
10-12	1570a	3650b	5430c
12-14	1540a	3600b	5410c
14-16	1600a	3320b	4900c
16-18	1470a	3040b	4420c
18-20	1500a	2780b	4270c
20-22	1800a	2880b	3890c
22-24	2140a	2800ab	3410b
24-26	2380	2870	3150
26-28	2530	2980	2940
28-30	2500	2880	2940
30-32	2570	2720	3080
32-34	2500a	2600a	3330b
34-36	2560	2730	3290
36-38	2630	2840	3270

*Rows with the same letter or no letter are not significantly different at the 5% level.

TABLE III

Cone penetrometer index (kPa) for silt loam soil, 1986

Depth (cm)	Compaction level (tonne) <4.5	8.0	12.5
0-2	238	246	246
2-4	442	504	483
4-6	592	633	638
6-8	687	715	704
8-10	863	829	817
10-12	1104	1150	1121
12-14	1425	1546	1629
14-16	1596	1800	1888
16-18	1704a*	1983ab	2171b
18-20	1704a	2025ab	2350b
20-22	1567a	1908ab	2292b
22-24	1333a	1688ab	2104b
24-26	1271a	1383a	1992b
26-28	1221a	1408a	1796b
28-30	1163a	1329ab	1588b
30-32	1142a	1333ab	1504b
32-34	1158a	1417ab	1513b
34-36	1158a	1454ab	1546b
36-38	1221a	1429ab	1621b
38-40	1217a	1413ab	1642a
40-42	1233a	1367a	1625
42-44	1296a	1442ab	1596b
44-46	1317a	1467ab	1625b
46-48	1433	1463	1650
48-50	1496	1475	1667
50-52	1542	1483	1704
52-54	1542	1529	1721
54-56	1596	1629	1692

*Rows with the same letter or no letter are not significantly different at the 5% level.

TABLE IV

Cone penetrometer index (kPa) for silty clay soil, 1986

Depth (cm)	Compaction level (tonne) <4.5	8.0	12.5
0-2	312	346	267
2-4	671	679	554
4-6	996	913	900
6-8	1317	1242	1404
8-10	1413	1550	1608
10-12	1321	1658	1667
12-14	1267	1483	1542
14-16	1142	1363	1646
16-18	1014	1242	1721
18-20	808a*	1100ab	1539b
20-22	833a	1463ab	1725b
22-24	958a	1642ab	1904b
24-26	1108a	1721ab	2271b
26-28	1446a	1725b	2425b
28-30	1708	1846ab	2454b
30-32	1750a	1883ab	2400b
32-34	1721a	1829ab	2263b
34-36	1621	1821	2100
36-38	1367	1983	2008
38-40	1525	2058	2008
40-42	1604	1883	2004
42-44	1513	1871	2096
44-46	1479	1783	2108
46-48	1492	1871	1975
48-50	1450	1808	1829
50-52	1613	1733	1721

*Rows with the same letter or no letter are not significantly different at the 5% level.

TABLE V

Mature plant height (cm)

Soil	Compaction level	Year 1983	1984	1985	1986
Silt	1*	228	241a**	215a	276ab
loam	2	205	237b	200a	280a
	3	192	228b	199b	269b
Silty	1	227	236a	161b	243a
clay	2	202	224b	177a	223b
	3	175	224b	161b	229b

* Treatment numbers 1, 2, and 3 are the control (no compaction), tractor (8 t), and combine (12.5 t)/liquid manure spreader(12.5 t) compacted, respectively.

**Plant height values at a given site for a particular year with the same letter are not significantly different at the 0.05 level.

TABLE VI

Grain yield at 15.5% moisture content (kg/ha)

Soil	Compaction level	Year 1983	1984	1985	1986
Silt	1*	6.65	10.10a**	7.56	10.50
loam	2	6.39	9.59ab	8.00	11.10
	3	5.74	9.21a	7.51	10.82
SD***		0.83	0.63	0.83	0.42
		ns		ns	ns
Silty	1	7.54a	10.87	5.30	7.78
clay	2	6.46ab	10.81	4.72	7.08
	3	4.32b	10.92	5.08	6.81
SD		1.66	0.85	1.24	1.30
			ns	ns	ns

* Treatment numbers 1, 2, and 3 are the control (no compaction), tractor (8 t), and combine (12.5 t)/liquid manure spreader(12.5 t) compacted, respectively.

** Grain yields at a given site for a particular year with the same letter are not significantly different at the 0.05 level.

***SD = significant difference; ns = not significant.

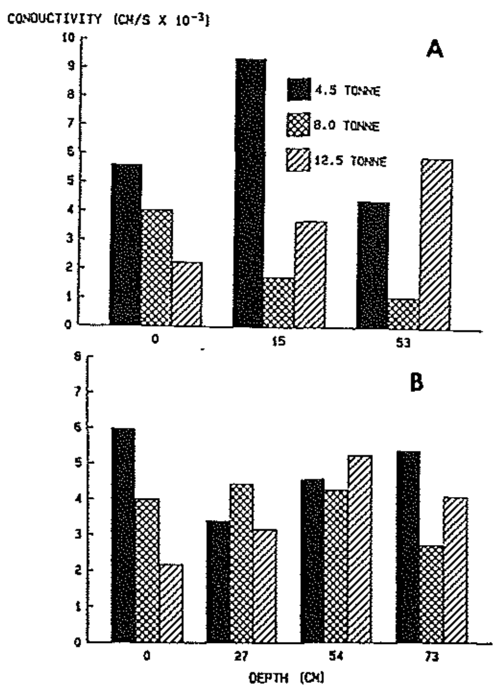

Figure 1. Hydraulic conductivity of saturated soil cores for the (A) silt loam and (B) silty clay sites.

SOIL STRENGTH AND CONSOLIDATION OF THE NEAR SURFACE ZONE OF BENCHMARK SOILS

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ABSTRACT

Most agricultural tractors exert a load on the soil of 50 to 120 kPa. Heavy harvest equipment can exert loads up to 300 kPa. Most soil compaction research to date has emphasized maximum loads for engineering applications. In agricultural applications, increases in bulk density caused by moderate loads can drastically affect soil physical and biological processes. Compaction characteristics were determined for A- and B-horizons of 16 soil series representing seven soil orders. A plot of bulk density vs applied load was used to develop soil compression curves for three soil water regimes. The regimes were satiated water content (wet), -10 kPa water potential (moist), and water content at the time of sampling (dry). The load range for small and medium size tractors coincides with the transition zone between the secondary and virgin compression curves. In general, the drier soils developed smaller bulk densities per applied load and the change in bulk density with increased load was less. However, small loads could cause a relatively high bulk density with wet soil.

INTRODUCTION

Compaction of agricultural soil is of concern because of increased use of heavy field equipment. Many field tractors and harvest equipment are heavy enough to have an immediate effect on the surface tilled layer and on the untilled soil below. The degree of soil compactness influences the soil environment and is therefore important to plant and microbial metabolic processes. Important phenomena in the soil affected by compaction are content and rate of conduction of water, heat, and gasses and the strength of soil.

The most common uses of soil compaction data are for engineering applications. Larson et al. (1980) used a wide variety of agricultural soils to compare changes in bulk density and porosity resulting from an applied mechanical stress.

The objectives of this study were to determine compression characteristics of A- and B- horizons for a wide range of soils and to relate the slope of the soil compression curve between 50 and 300 kPa to measured physical properties. We hypothesize that A- and B- horizons have different compression characteristics due to variation in texture and organic carbon content.

METHODS

Soil samples from A-horizon and B-horizons were obtained from seven soil orders across the continental USA and from the A-horizon from two soil orders in Hawaii (Table I). Soil at the field water content was passed through a 2-mm sieve. Compression curves were developed from a plot of bulk density versus the logarithm of applied load for each soil at satiated water content (wet), -10 kPa water potential (moist), and water content at the time of sampling (dry). Compression tests were conducted according to ASTM standards (ASTM D 2435-85).

Loads for agricultural equipment were calculated from estimated total axle weight and tire contact area. The smallest load considered was a 7500 kg tractor with dual tires (Td) which provided a load of 51 kPa. The same tractor with single tires (Ts) provided a load of 96 kPa. A 8600 kg 4-wheel drive tractor (4-w) with single tires provided a load of 110 kPa. Harvest equipment (H)weighing 18 Mg/axle (Voorhees et al., 1986) could provide a load as great as 300 kPa. A 12.1 m^3 liquid manure tank, when filled to capacity, would provide approximately 240 kPa load to the soil. Nebraska Tractor Test Laboratory reports were the source of tractor data.

Table I

Summary of classification and sampling location for benchmark soils.

Sym	Great or subgroup	Series	Mineralogy	Location
M1	Typic Haploxeroll	Walla Walla	Mixed	Oregon
M2	Udic Haploboroll	Barnes	Mixed	North Dakota
M3	Typic Hapludoll	Clarion	Mixed	Iowa
M4	Torrertic Paleustoll	Pullman	Mont.	Texas
M5	Typic Argiudoll	Sharpsburg	Mont.	Nebraska
A1	Typic Paleudalf	Crider	Mixed	Kentucky
A2	Typic Hapludalf	Miami	Mixed	Indiana
A3	Typic Xerorthent	Yolo	Mixed	California
U1	Typic Paleudult	Frederick	Mixed	Virginia
U2	Typic Hapludult	Cecil	Kaolinitic	North Carolina
U3	Typic Paleaquult	Rains	Siliceous	South Carolina
R1	Typic Haplargid	Mohave	Mixed	Arizona
R2	Ustollic Haplargid	Fort Collins	Mixed	Colorado
E1	Typic Ustipsamment	Valentine	Mixed	Nebraska
V1	Udic Pellustert	Houston Black	Mont.	Texas
S1	Dystril Eutrochrept	Caribou	Mixed	Maine
O1	Ustoxic Humitropept	Kole Kole	Oxidic	Hawaii
I1	Tropeptic Eutrustox	Wahiawa	Kaolinitic	Hawaii

M = Mollisol, A = Alfisol, U = Ultisol, R = Aridisol, E = Entisol, V = Vertisol, S = Spodosol, O = Oxisol, and I =Inceptisol.

Optimum water content for maximum bulk density was determined using Proctor density procedures (ASTM D 698-85). Soil strength was determined at all water contents in the Proctor density curves with a hand-held flat tip penetrometer. Water filled pore space was calculated for the maximum bulk density. Particle size distribution, organic carbon content and other pertinent chemical and physical properties were evaluated at the USDA Soil Conservation Service, National Soil Survey Laboratory in Lincoln, NE (Soil Survey Staff, 1984)

RESULTS

Compression curves using average soil bulk density for five Mollisols, three Ultisols, and two Aridisols are illustrated in Fig. 1 for the A- and B- horizons under wet, moist and dry conditions. Bulk density for wet soil increased linearly with increased load between 12 and 766 kPa. The average slope of the line was greatest for Mollisols and least for Ultisols. The slope of the compression curve generally decreased with decreased water content and became non-linear. The greatest change in slope is exhibited from 48 to 192 kPa for moist conditions where the slope was actually steeper than for wet conditions. From 192 to 766 kPa the moist condition of all soils and the dry condition for the Mollisols generally paralleled the corresponding wet compression curve.

The relationship between slope of the compression curve and clay for Mollisols, Entisols, Spodosols and Vertisols having less than 33% clay are shown in Table II. No statistical relationships were identified for soils having greater than 33 % clay because of limited sample size. The slope of the compression curve used in this analysis is representative of loads ranging from approximately 50 to 300 kPa. The regression coefficients indicate a greater slope for the B- horizon than for the A- horizon. The slopes according to water regime ranked moist > wet > dry. The best fit regression equations occurred at the wet and moist water regimes.

Maximum bulk density developed at high loads for the B- horizon of the Aridisols (Fig. 1). Greatest differences in bulk density between A- and B- horizons for wet conditions were Ultisols>Aridisols>Mollisols . Bulk densities for the two horizons were the same over most of the load range for Mollisols. For loads less than 75 kPa, soils for the moist regime exhibited lower bulk densities than those for the wet regime. Dry regime soils had lowest bulk densities over the entire range of applied loads.

Proctor density curves were developed to identify optimum water content for maximum bulk density (data not shown). Generally, maximum bulk density was less for the A- horizon than for the B- horizon. This difference was 0.10 Mg/m^3 or more for Vertisols and the Spodosol. Among all soils, highest bulk densities, 1.80 to 1.85 Mg/m^3, were associated with the Aridisol and Entisol. Lowest optimum water content for compaction was 0.11 kg/kg in the Entisol B- horizon, while highest was 0.30 kg/kg for Vertisol B- and Spodosol B- horizons. There was no consistent trend between soil strength and bulk density or soil strength and optimum water content for the A- horizon as compared to the B- horizon.

Water filled pore space at optimum water content for maximum density was also calculated (data not shown). Water filled pore space was about 60 % for Entisol and 80 to 90 % for the other soil orders. Concepts of water filled pore space for these soil as they relate to microbial activity are further developed by Doran et al. (1988). Organic carbon content of the B- horizon was always less than that for the A- horizon while clay content was generally greater.

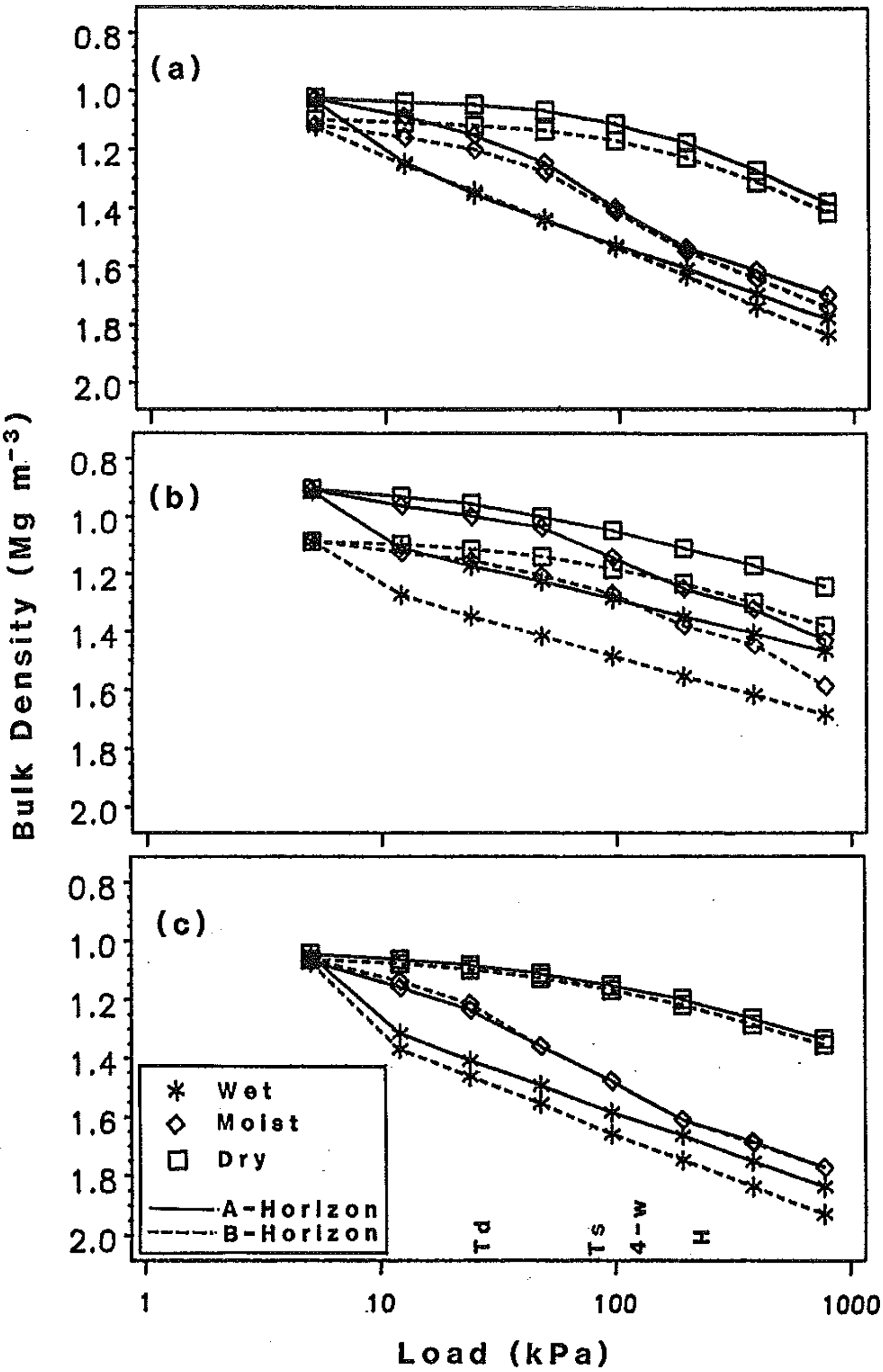

Fig. 1. Soil compression for (a) Mollisols, (b) Ultisols, and (c) Aridisols for A- and B-horizons for wet, moist, and dry soil water status.

Table II

Relationship between slope of the compression curve for load of 50 to 300 kPa and clay content for three water regimes of the A- and B- horizon of Mollisols, Entisols, Spodosols and Vertisols having less than 33% clay.

Water Status	Horizon	Equation	R^2	P>F
Wet	A	Y=0.0585+0.0091X	0.868	0.020
	B	Y=0.0737+0.0106X	0.930	0.008
Moist	A	Y=0.0306+0.0139X	0.760	0.054
	B	Y=0.0447+0.0155X	0.854	0.028
Dry	A	Y=0.177+0.0018X	0.456	0.211
	B	Y=0.115+0.0052X	0.854	0.025

DISCUSSION

Compression characteristics and other measures of soil strength are of greatest value to soil management when they are derived for the range of conditions found in agricultural applications. Several loads for field size tractors were identified in Fig. 1.

Most soil compression measurements are used for engineering purposes and are intended to determine maximum bearing strength associated with the virgin compression curve. The load at which the virgin compression curve begins is shifted to the right as soil conditions become drier. Load estimates of agricultural equipment in the 50 to 300 kPa range frequently coincide with a transition zone between secondary and virgin compression curves. This is particularly true for drier soils conditions. For a dry water regime, Larson et al. (1980) showed that the virgin compression curve started at about 100 kPa load for a Mollisol and at more than 300 kPa for an Oxisol. They found that the transition zone, over a wide range of water contents , was from 50 to 100 kPa for the Mollisol and from 100 to 300 kPa for the Oxisol.

The maximum compression curve slope for the moist water regime of soils in Fig. 1 was from 48 to 192 kPa. This is the load range of many small to medium sized tractors used with 6-row field implements. Soil series from other soil orders (data not shown) exhibited similar compression characteristics in the 48 to 192 kPa load range.

Clay and water content were two major factors influencing the shape of the compression curve. The regression equations relating clay content to slope of the compression curve in the 50 to 300 kPa range indicate that soils are more susceptible to compaction and that the differential increase in bulk density will be greater for moist than for wet and dry conditions. The slope of the regression equations were consistently higher for the B- horizon than for the A- horizon because of higher clay and lower organic carbon content.

These general curves for three soil groups indicate the wide range in bulk density expected with a specific load from wet to fairly dry soil conditions. Most soil properties generally exhibited greater differences among soil series within a soil order than between orders. Therefore, most soil investigations involving compaction characteristics should be soil specific. This points to a need to include soil specific information in soil management data bases.

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SOIL BEHAVIOUR BELOW A SHEARING ELEMENT

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ABSTRACT

The movement of soil below a shearing element was studied. Prior to shearing the soil was prepared by insertion of a vertical column of dry yellow peas. The peas were individually labelled and their positions recorded. After shearing the peas were carefully excavated and their new positions recorded. The results show that the shear strain extends vertically into the soil to a depth of about 20 mm. Furthermore, it was attempted to measure the change in dry bulk density due to the soil shear. The results indicated a slight increase in soil density due to shear.

INTRODUCTION

When soil is subjected to a shear stress as existing below a slipping wheel it will normally fail. However, not very much work has been done concerning the resulting change in the soil's state. Raghavan and McKyes (1977) found increases in dry bulk density between 20 and 40 kg/m^3 when sandy loam soil was sheared in a special shear box in the laboratory. They note, however, that considerable higher density increases was observed in the field. Later they (Raghavan et al., 1978) conducted similar studies on clay soil. Also under these conditions they found increases in soil density albeit not so pronounced as for the sandy soil.

STRESS FIELD

As a shear stress is set up by a running gear the principal stresses in the soil below changes their directions and magnitude. The next two sections analyses the stress field and its possible influence on the soil's state.

Principal stresses below a shearing element

For a static load the isobars of the vertical normal stress field in the soil forms egg-shaped curves as shown by Söhne (1953). The highest normal stresses occur just below the load and decreases with depth. For a slipping wheel that introduces both shear and normal stress to the soil surface the shape of the isobars is more complicated. Nevertheless it is evident that the shear stress increases the magnitude of the major principal stress. This may be shown by means of Mohr's stress circle.

Fig. 1 shows the stress situation for a soil at failure. From the Mohr-Coulomb failure theory it is known that the major principle stress plane slopes 45 deg. plus half of the angle of internal shearing resistance to the failure plane. Assuming a soil with a cohesion of 15 kPa, an angle of internal shearing resistance of 30 deg. and a vertical normal stress of 100 kPa the shear stress at failure is 35 kPa at the surface. Olsen (1988) calculated the major principle stress to 226 kPa or more than double the magnitude of the surface normal stress. If the major principle stress is mainly responsible for soil compaction as proposed by Koolen and Kuipers (1983) it is understood that shear stress may affect the compaction of the top soil by its influence on the major principal stress.

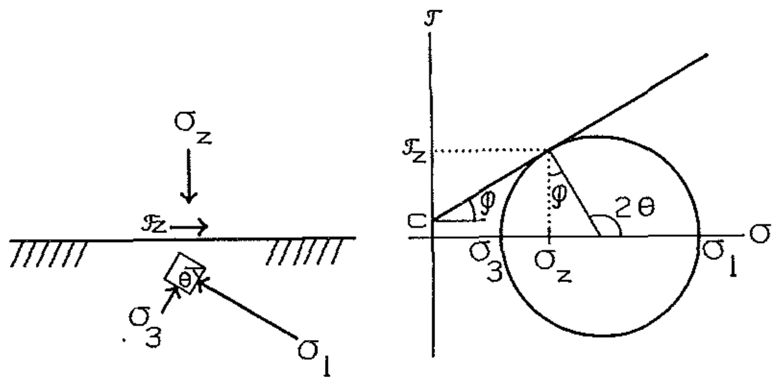

Fig. 1. Principal stresses σ_1 and σ_3 at failure for a vertical normal stress σ_z and maximum shear stress τ_z. The soil's cohesion is denoted c, the angle of internal shearing resistance: ϕ and the angle between the horizontal failure plane and the σ_1-plane is called θ.

Shear stresses below a slipping wheel

When the soil is subjected to a heavy load a compacted soil wedge is formed just below the loading element. As this eventually sinks into the soil the wedge will follow as if it was part of the element.

It may be assumed that the wedge not only follows the loading element in its downward motion but also - at least to some extent - will stick to the element in the case of a horizontal motion. Reece (1964) performed some tests with a rectangular shear plate where he - in some of the experiments - fitted a suitable triangular woodden bar covered with sandpaper below the shear plate. The results indicated no difference whether the wodden bar was fitted or not. Even if this is not a strict proof, it is an indication that the wedge may follow the element in its horizontal motion.

For agricultural operations the total bearing capacity of the soil is seldom mobilized. However, the triangular wedge does obviously not develop suddenly at a certain threshold load. It is possible to suggest a gradual build-up in the formation of the wedge below an element as the load increases: First the soil layer just below the element will be somewhat compacted. As this soil layer compacts its compressive strength increases and it will therefore, to some degree, transfer the vertical stress unchanged to the soil just below. Thus, the soil just below the compacted zone will be subject to an increased normal stress field. The stress generating lower surface of the element has, so to say, been moved downwards due to the compacted layer just below the element. Therefore, the next soil layer will compact and - in turn -behave as fitted to the element and the process proceeds. Fig. 2 is an attempt to illustrate the compaction process outlined above. For a moderate loading the process may be imagined to cease at one of the curves inside the triangle.

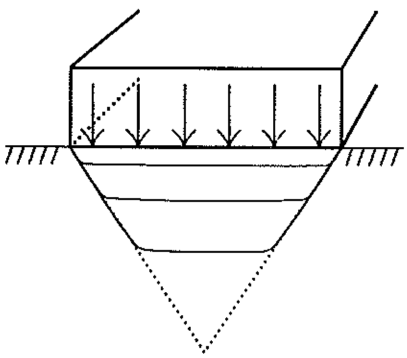

Fig. 2. The author's concept of the soil compaction process below a strip-load. The curves within the triangle show progressive developments of the compaction process.

Considering Reece's (1964) argument that the compacted wedge will follow the loading element even in a shearing or slipping action it is possible to suggest that the soil shear will take place at a depth dependent on the vertical load. Thus, the higher the vertical load the deeper into the soil the shear failure plane will be located.

Another question concerns the behaviour of the soil just below the failure plane whether that occurs just below the loading element or below the compacted soil layer. In this zone the shear stress is smaller than the soil strength because shear failure has already occurred just on top of the zone. In particular, the interesting question is to which depth the soil is affected i.e. deformed, even if no large displacements have occurred.

EXPERIMENTS

Field experiments were carried out in order to find the influence of the shear strain on the soil density. Also some simple experiments were done with a shear plate to investigate the depth to which the soil is affected.

Soil density measurements

Measurings of the change in dry bulk density was performed in the laboratory using a soil bin filled with a loam type of soil with a moisture content of 9 percent. The soil had been sieved through a 10 mm mesh so that even moderate stones were removed. A torsional shearing device described in Olsen (1984) was used to apply the normal and shear stresses. After the treatment soil samples were taken using rings of 72 mm diameter and 50 mm height.

Two normal stresses of 45 and 100 kPa were used and for each stress level three displacements of 5, 10 and 20 cm were applied. The results revealed no difference in dry bulk density as function of shear displacement. Therefore, all density results for the various displacements were lumped together. Table I shows the results after this grouping.

Table I. Change in soil's dry bulk density as a result of shearing. The difference in densities for the 45 kPa normal stress is significant on a 0.01 percent level. For 100 kPa there is no significant difference

Normal stress	Without shear	With shear
45 kPa	1326 kg/m^3	1369 kg/m^3
100 kPa	1363 kg/m^3	1369 kg/m^3

From Table I it is noted that the shear process seems to affect the soil's density at the low normal stress although to a quite moderate degree. At the high normal stress level no influence was found.

Shear depth measurements

In order to obtain some information about the depth to which the shear stress extends some simple experiments were carried out. The tests were done in a field with sandy loam soil. The moisture content was 20 percent on dry base which was close to field capacity. The cohesion was 15 kPa and the angle of internal shearing resistance was 33 deg. measured in the field by means of the torsional shearing device.

The soil was prepared by making a hole 8 mm in diameter and 80 to 100 mm deep. The hole was filled with labelled dried yellow peas so that pea no. 1 was in the bottom with the numbers incrementing upwards. For each pea its depth was recorded. When the hole was filled to within about 15 mm from the surface a simple shear plate was placed over the pea column in such a way that the column was in the middle between two grousers. The plate was loaded with an appropriate weight and pulled a distance of approximately 15 cm. After the shearing procedure the sinkage of the plate was recorded. Then the peas were carefully excavated and their new positions recorded.

Fig. 3 shows some typical results. It is seen that the peas were displaced in very much the same way independent of the normal stress. It is especially interesting to note that the peas are displaced down to a depth of only 20 mm below the final depth of the grousers lower edge. This observation suggests that the shear stress effect does not reach very deep into the soil.

The somewhat odd displacement of pea no. 5 from the top in the lower diagram in Fig. 3 may be due to the formation of a compacted layer below the grousers as shown in Fig. 2. If this pea was trapped in such a layer it would follow the horizontal movement of the shear plate right to the end of the movement. Obviously, it did not do so which may be due to break-down of the front end of the layer just before the shearing stopped.

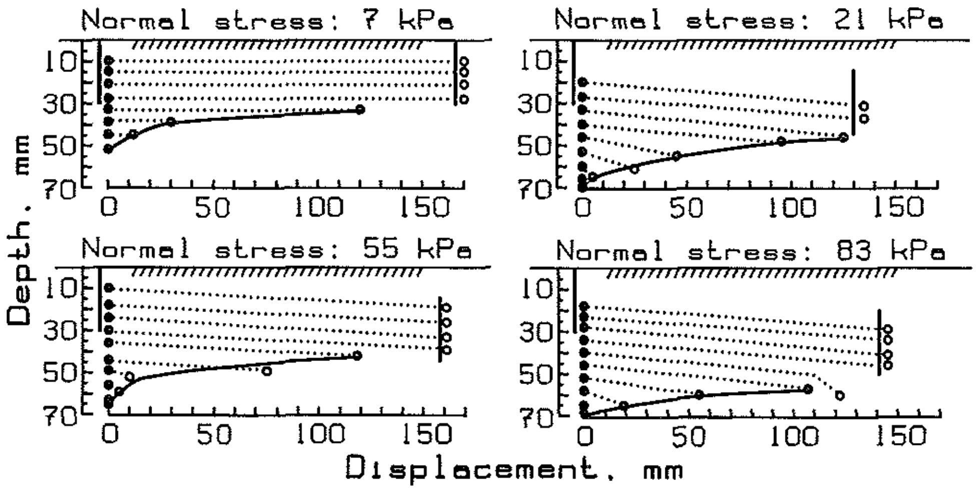

Fig. 3. Results from experiments with shearing of a soil containing labelled peas. The initial positions of the peas are shown as filled circles and their final positions as hollow circles. The fat vertical lines indicate initial and final depth of the shear plate's grousers. The dotted lines bind together the individual peas in their initial and final positions. However, it should be noted that this does not necessarily mean that the peas have moved along these lines. Nothing is known about the paths for the individual peas.

DISCUSSION

It proved difficult to use a torsional shearing device for the study of the shearing's compaction effect. As shown in Fig. 2 the formation of a wedge below the annulus may be expected at higher normal loads. Due to the rotational movement of the annulus this wedge will probably be very unstable. It may break down and build up again in an uncontrolled manner.

Concerning the results in Table I for the low normal stress it is impossible to state how much of the increase in density that should be ascribed to the formation of a wedge due to normal stress and how much is due to rearrangement of soil particles close to the shear failure zone. Because the soil sampling rings have a diameter of about same size as the width of the shear annulus a soil sample will incorporate zones of both kinds of compaction mechanisms.

SUMMMARY

1 The shear stress introduced below a shearing element has a large effect on the magnitude of the major principle stress in the soil just below the element.

2 It is suggested that the compacted soil layer formed just below a loaded element will, to some degree, follow the element during its horizontal movement.

3 Therefore, the shear failure zone will occur at some depth in the soil dependent on the normal load on the shearing element.

4 The soil's density seems to increase only moderately due to shear.

5 Field tests with a simple shear plate indicated that shear displacements occurred into the soil to a depth of only 2 cm below the grousers.

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THE EFFECTS OF VEHICULAR TRAFFIC ON THE GROWTH PATTERN OF MAIZE ON A TROPICAL ALFISOL.

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ABSTRACT

Plots subjected to 0, 2, 5, 10 and 15 passes of the tractor were used to study the effects of vehicular traffic on the growth pattern of maize on a sandy loam soil in the rain forest region of Nigeria.

Results show a general delay in seedling emergence as a result of the high mechanical impedence due to vehicular passes. The impedence also caused significant reductions in root growth, dry weight, penetration rate and density. There was reduction in grain yield as a result of vehicular passes. Yield was in the order 0>2>5>10>15 passes.

INTRODUCTION

Soil degradation can be classified into three major groups namely; physical, chemical and biological degradation. According to Ofori and Saint Anna (1985), physical degradation starts with the clearing of vegetation for agricultural development. Under the system of shifting cultivation widely practised in the developing countries, land clearing techniques have no direct effect on soil compaction. The implements are simple - matchets and hoes. Recent trends in large scale farming projects in the developing countries involve the use of inappropriate heavy machinery causing soil compaction and subsequently resulting in reduced water infiltration and increased surface runoff. The increasing use of heavy tillage machinery as well as vehicular traffic in farm operations also result in soil compaction which restricts rooting depth of crops and rainfall infiltration. Rapid deterioration in soil properties and consequently crop growth and yield following mechanical land clearing has been reported (Vender Weert 1974; Seubert et. al., 1977; Lal and Cummings, 1979; and Hulugalle et.al. 1984a) According to Free (1953) tractor tyres and machine tillage operations created a denser layer at the 8 - 12 inch depth and a much higher density in the wheel tracks between the rows of potatoe plants. Vomicil et. al. (1958), Bateman (1959), Bourget et. al. (1961) etc have reported adverse effects of vehicular traffic on some soil physical properties.

That soil compaction has qualitative effects upon the growth, maturity and general physiological behaviour of plants has been observed and reported in the literature (Flocker et. al. 1958; Rosenberg and Willits, 1962; Wittsell and Hobbs, 1965; Morgan et. al. 1966). The need to increase food and other agricultural production in the developing world cannot be overemphasised. At the same time, realistic and careful planning of land development and the choice of appropriate technology should receive the utmost consideration if vast areas of agricultural land are to be developed and their productivity maintained.

Materials and Methods:

The study was carried out at the University of Ibadan, Nigeria. Ibadan has the coordinates of 7.22°N and 3.58°E and is located in the rainforest region of southwestern Nigeria. The annual rainfall ranges between 1200 and 1600mm.

The tests were carried out on a well-drained sandy loam soil belonging to the Iwo series (Smyth and Mongomerry, 1962) and is classified as ferric Iuvisol (FAO). The subsoil is sandy clay to clayey sand and a gravel horizon of angular and subangular quartz gravels exists immediately below the subsoil at the 47 - 72 cm depth. The proportion of sand, silt and clay at the 0 - 15 cm depth is 70.4, 12.4 and 17.2 percent respectively.

Land Preparation:

The experiments were located on a 20 x 60m area which had been under maize cultivation after clearing from secondary forest. The area was divided into 3 blocks of 20 x 18m leaving a 3m headland between the blocks. Each block was then subdivided into 5 plots of 2.5 x 18m with about 2m wide alley seperating one plot from the other.

There were four treatments comprising of 0, 2, 5, 10 and 15 passes of the tractor. The logistics behind these machine passes was based on the determination that under conventional farming operations, a rear wheel could traverse a corn field about 12-15 times if seed-bed preparation, seeding and fertilizer application, spraying, weeding, and harvesting were to be mechanised. Reduced tillage and other machine operations would reduce the number of vehicular passes.

The various compaction treatments were achieved by driving a Massey Ferguson (MF 260) tractor with a design weight of 2,082 kg, and dead weight of 216kg attached to the tractor, forth and back on the each plot area to the required number of passes. The rated power output of the tractor was 71.0 KW. The front and rear tyre sizes were 7.5/16 and 18.0/26.0 respectively. The treatments were arranged in a randomised complete block design.

The seeding (maize) operation was done manually on all the plots in four parallel length-wise rows with a 75 x 30 cm spacing. Two seeds were sown per hill. These were later thinned to one per hill 10 days after seedling emergence. Five weeks after planting 75kg N as urea was applied by broadcasting. Weeding was done manually 3 and 7 weeks after planting.

Evaluation of the experiment was divided primarily into plant responses and soil strength. Plant responses were determined by counting, measuring, weighing and visual observations. Of particular interests were seedling emergence, plant heights, root growth, flowering and fruiting patterns and crop yield. The methods are very standard and need not be described here.

Bulk density and penetration resistance were used in evaluating the changes in soil physical conditions. Penetration resistance was measured with a recording soil penetrometer in 5cm depth intervals to 15cm depth. Measurements were carried out at 8 locations per plot before and after applying the treatments and weekly thereafter.

Results and discussions:

Seedling emergence:

Seedling emergence was observed in the 0 and 2 - pass plots four days after planting. There was a 3-day delay of seedling emergence in the plots subjected to 10 and 15 passes. This difference was significant at 5 per cent indicating that vehicular traffic has an adverse effect on the germination of maize. Seedling emergence in the 5-pass plot was delayed by 2 days. This difference was also significant.

Table 1 shows the effects of vehicular traffic on some emergence parameters namely rate of emergence, time to reach 50% ultimate emergence, percentage ultimate emergence and mean period of ultimate emergence. The rate and percentage of emergence was in the order: 0 pass>5 passes>10 passes>15 passes. The time to reach 50 percent ultimate emergence was prolonged by an average of 1.21 days in the compacted plots while the time to reach ultimate emergence was prolonged by as much as 4.5 days in the 15 - pass plots. Ultimate emergence was 86.51, 79.00, 67.12, 57.25 and 53.25 per-cent in the 0, 2, 5, 10 and 15 pass plots respectively. Since the seeds were sown in about 3 cm holes which were backfilled with lightly pressed soil, penetration resistance in the holes might not have constituted a problem for germination and shoot growth in the compacted soils. The attendant decreases in permeability to gaseous exchange and water as well as alterations in thermal relations usually associated with soil compaction could explain the differences in seedling emergence.

Table 1: Vehicular Traffic as affecting Seedling Emergence

Treatment	Rate of Emergence (per day)	Time to 50% emergence (days)	% Ultimate emergence	Mean Period of ultimate Emergence (days)
0	6.35	3.75	86.51	9.30
2	5.64	4.00	79.00	9.60
5	4.94	4.65	63.12	11.80
10	3.42	5.79	57.25	12.70
15	3.01	6.41	53.25	13.80

Root growth:

The effects of vehicular traffic on the rooting habits of maize is shown in Table 2. Generally, vehicular traffic affected markedly penetration rate, and root weight in the different treatments. For example, two weeks after planting root length in the 0 and 2 pass treatments were 25 and 20cm respectively. However four weeks after planting, root length in the zero pass was 54cm while only 37cm in the 2 - pass treatment. The difference was significant at 5%. There were significant reductions in the penetration rates in the 10 and 15 pass plots. The depth of penetration was less than 15cm in both treatments two weeks after planting and still less than 20cm four weeks after planting. Root length density increased as soil resistance increased due to increased production of first order laterals and decreased rooting depth.

Table 2: Effect of vehicular traffic on root development four weeks after planting.

Root characteristics	Treatments				
	0	2	5	10	15
Root length (cm)	54.2	37.3	23.0	18.7	18.2
Lateral root extension (cm)	30.3	26.1	16.5	14.3	13.6
Root dry wt.(g/500cm^3 of soil) 0 - 10cm	1.83	1.36	1.01	0.83	0.81

Lateral root system development was more pronounced in the 0 and 2 - pass treatments than in the 5, 10 and 15 pass plots. The lateral roots in the 10 and 15 pass plots remained within the 10 - 20cm range throughout the sampling period while in the 0 and 2 - pass treatments the lateral roots were 30 and 26cm long four weeks after planting. Further sampling after four weeks however showed a reduction in the lengths of the lateral roots probably due to the death of seminal roots with time. These differences in root system development can be attributed to changes in penetration resistance and bulk density associated with compaction by vehicular traffic.

Gross root morphological deffects were observed in response to increased physical resistance. As soil resistance increased due to vehicular traffic, the primary roots became more twisted and the length ratio of the first order laterals to primary roots increased.

Plant growth and vigour:

The 0 - pass treatment had more vigorous growth than the treated plots (Table 3):

Table 3: Effect of vehicular traffic on the height of maize (cm)

Time in weeks	Treatments				
	0	2	5	10	15
2 weeks	35.6	30.4	25.3	23.5	22.6
4 weeks	100.2	90.3	65.8	58.7	50.1
6 weeks	163.5	152.6	98.4	90.3	85.4
8 weeks	175.8	163.7	132.7	123.6	115.2

There was no significant difference however between the heights of plants in the 0 and 2 pass plots eventhough the 0-pass plants were taller. Also there was no significant difference between plant height in the 5, 10 and 15 pass treatments. Tip-burning and chlorotic symptons especially in young leaves was observed to increase with increasing compaction. This may be partly due restricted root growth associated with compaction.

Dry-matter production was significantly affected by compaction. The Dry-matter production six weeks after planting was 245.6, 230.1, 160.7 150.0 and 146.3 gm per plant for 0, 2, 5, 10 and 15 - pass treatments respectively. Compared with the 0-pass, flowering and silking were delayed for 2 days, 5 days and 6 days in the 5, 10 and 15 pass treatments respectively. The differences were significant at 5 percent.

Grain Yield:

Maize yield averaged, 4.1, 3.7, 2.6, 2.0 and 1.9 tons/ha for 0, 2, 5, 10 and 15 passes respectively. There is a significant difference between grain yields in the less compacted plots(0 and 2 passes) and the more heavily compacted plots. Eventhough the difference in yield between the 0 and 2 passes was not significant, however yield in the 0-pass was more than 10 percent higher.

Conclusions;

Results of this work have shown that vehicular traffic adversely affects the different stages of maize growth on a tropical alfisol. There is a significant reduction in root growth and rate of penetration due to the mechanical impedance created by vehicular traffic. This reduction in root activity contributed to reduced plant growth and eventual low yield.

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TIMELINESS AND MACHINE PERFORMANCE BENEFITS FROM CONTROLLED TRAFFIC SYSTEMS IN SUGAR BEET.

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ABSTRACT

Trials on a silty clay loam soil indicate that use of controlled traffic systems could advance drilling following wet periods by up to 3 days. Operating harvesters and trailers on traffic lanes in difficult seasons, reduces soil compaction and can reduce rolling resistance by up to 60%. Beet grown under controlled traffic systems are easier to harvest. Proposals are made for an improved traffic lane profile.

INTRODUCTION

Wheel traffic influences the following factors which affect the overall profitability of the sugar beet crop:

timing of establishment, development of good quality beet, ease of harvesting in difficult seasons, and soil conditions for the following crop.

Excessive soil compaction from wheeled traffic in the crop growing area can cause establishment problems and impede later root development. To minimise these effects, seedbed preparation is usually delayed on wet soils to allow an adequate drying period, before trafficking and this may reduce yields. Harvester and transport traffic in wet harvests often suffer from excessive wheel sinkage which increases rolling resistance and causes severe soil compaction problems. This slows down harvest and creates problems for the following crop. In very dry soils, beet grown under compacted conditions can be extremely difficult to harvest.

Most of these problems could be avoided or significantly reduced, by confining all traffic to prepared traffic lanes. This paper quantifies some of the timeliness and machine performance benefits that could accrue, from such a system.

TIMELINESS BENEFITS FOR CROP ESTABLISHMENT

Under UK conditions, beet yields decline by 4-5% for each weeks' delay in establishment after the optimum drilling period. Soil moisture contents at this time are high, rainstorms are frequent and delays in drying are common in many years. The shorter the delay time needed following rainfall, before drilling, the greater the chance of crop establishment during the optimum drilling period. The delay time depends upon weather conditions, the amount of soil preparation work required and the maximum moisture content at which the soil can be worked and drilled. The degree of soil preparation required is dependent upon the tilth and levelness of the ploughed surface in spring, see Spoor and Godwin (1984). A level weathered surface can reduce seedbed preparation passes with tined implements from 3 to 1 or even zero passes.

Level ploughed surfaces are readily achievable during ploughing on coarser textured soils, but become more difficult to produce, as soils become heavier and wetter. In these latter situations, a further levelling operation may be required on the ploughing during autumn or winter, after some weathering, to produce the required condition. This can be achieved without compaction in the cropping area using controlled traffic systems.

The following results show that successful seedbed preparation and drilling can be achieved without detriment to the soil, rate of plant emergence or final plant population, at much higher soil moisture contents working from a traffic lane, than when wheels operate in the cropping area. The experiment assessed the daily performance of tine cultivators at different working depths, a crumbler roll and a drill on a silty clay loam soil as it dried from an initially wet condition. Figure 1, shows the moisture content changes with depth and time, as the soil dried from a condition where surface layer moisture contents were above field capacity. Shallow tine and crumbler operations were impossible on the first day, but it was just possible to direct drill seed at a depth of 40 mm. The ground driven drill used comprised of a backward raked coulter, concave press wheel fitted with scrapers, and a seed press wheel covered with a flexible tyre. Some soil pick up occurred on both the ground drive and press wheels.

Shallow 90° rake angle spring tines working at 60-70 mm depth to level a slightly uneven ploughed surface, operated satisfactorily on the second day, but the crumbler roll blocked. Drilling was not possible immediately behind the tines, due to the wet soil brought to the surface adhering to the drill. A short drying period between tining and drilling would have overcome this problem. Direct drilling was possible with minimal soil pick up. By the third day, soil in the top 20-30 mm had dried to the plastic limit and under these conditions the crumbler roll attached behind the shallow tines operated satisfactorily without blockage, as did the drill.

Deeper tining operations to 200 mm depth, to remove wheel compaction prior to drilling caused by random wheelings, generated unacceptable clods up to 150 mm long and 50 mm square during this 3 day period. These clod problems became

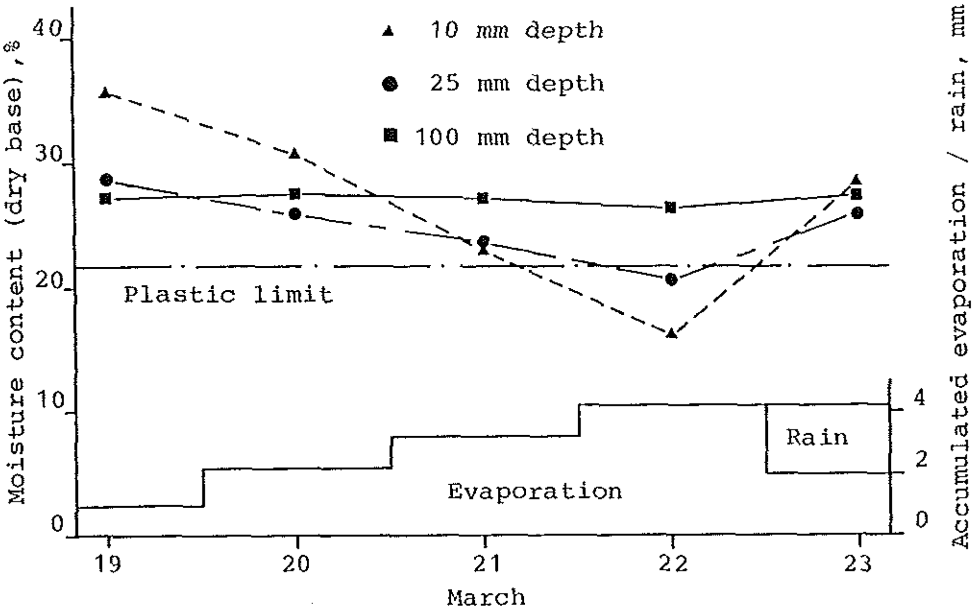

Fig.1, Soil profile moisture content changes with depth and time on drying.

less noticeable with time (on 5th day), but considerable additional soil working was required before satisfactory drilling could take place. Seedbed preparation operations with random wheelings would, therefore, have started on the 5th day, if rain had not intervened. The soil was then considered to be in an "acceptable" condition for working.

These trial results show that by adopting a controlled traffic system in these conditions, the delay time required before drilling can be reduced by up to 3 days, the actual time being dependent on the extent of cultivation necessary. A 4 day reduction proved possible where conditions were suited to direct drilling. It is interesting to note that the rainfall on the 5th and subsequent days prevented any further drilling for a period of 20 days.

MACHINE PERFORMANCE BENEFITS

Most current trailed sugar beet harvesters run with their wheels in lifted beet rows and due to the limited reach of most discharge elevators, trailers also have to run in the cropped area. This has severe implications for soil compaction, rolling resistance and traction requirements, particularly in wet seasons. To assess the potential performance benefits to be gained from operating with all wheels on traffic lanes, harvester and trailer force measurements were made on two soils under moist working conditions. The measurements were taken in both controlled traffic plots, where the cropped area had not been subjected to any wheelings and in random wheeled plots, where up to 6 wheel passes had been made in the cropped area prior to drilling. The horizontal forces required for lifting the sugar beet and for overcoming harvester and trailer rolling resistance are presented in Table 1.

Very large reductions in rolling resistance were achieved from operating on traffic lanes, particularly in the case of the trailers. The reductions were greatest, as would be expected, on the less consolidated controlled traffic plots. Harvester and trailer rolling resistance reductions ranged from between 25-30% and 40-60% on the controlled traffic plots to 10-15% and 10-25% on the random wheeled areas respectively. These results are equally applicable to those situations where compaction, caused by pre-drilling traffic not confined to traffic lanes, is minimal.

Harvester lifting forces on the controlled traffic plots on the silty clay loam site were actually higher than those on the random wheeled area. This was due to two factors, a significantly greater oppel wheel working depth (30-50 mm) due to increased harvester sinkage and better shaped, longer rooted beet, which required a higher pulling force to remove. The results suggest that the total harvester force may in some situations actually increase in a controlled traffic system, if harvester wheels are not confined to traffic lanes.

Another harvesting benefit from controlled traffic systems arises in very dry seasons, when beet anchored in compacted soil are extremely difficult to lift without root snapping. Beet growing in an unwheeled area can be harvested very easily under such conditions.

TABLE I Machine draught forces at harvest (kN)

Equipment	Clay		Silty Clay Loam	
	Wheelings			
	Controlled	Random	Controlled	Random
Harvester				
Lifting force	1.9	4.5	3.9	3.0
Rolling resistance				
on traffic lane	5.1	4.6	4.7	4.9
in cropped area	7.7	5.5	6.5	5.8
Total draught				
on traffic lane	7.0	9.1	8.6	7.9
in cropped area	9.6	10.0	10.4	8.8
Trailer (Capacity)	8 tonnes		11.5 tonnes	
Rolling resistance				
on traffic lane	4.9	4.1	3.4	4.3
in cropped area	8.2	4.5	8.3	5.6

Use of traffic lanes for the harvester and trailers offers, therefore, the opportunity to restrict compaction damage, reduce traction requirements in difficult seasons and to lift beet satisfactorily under very dry conditions.

TRAFFIC LANE PROFILE

Maximum benefit can only be derived from controlled traffic systems, if the traffic lanes themselves allow access over the widest range of moisture conditions and can support with minimum deformation, the loads to be applied. The common traffic lane section formed as a direct result of wheel sinkage, is shown in Figure 2a. This profile with its compacted surround encourages water to pond and infiltrate into the centre of the roadway. The resulting increase in moisture content in the central area reduces soil shear strength and bearing capacity, thus delaying subsequent operations and increasing the risk of further wheel sinkage. A change in profile is therefore required to discourage water entry into this central area.

Two major possibilities exist to drain water away from the traffic lane area. The first would be to form a raised traffic lane capable of shedding water sideways and the second to develop a profile similar to that shown in Figure 2b. In the latter drained profile, water is shed sideways by the cambered base to the free draining areas at either side. This profile has the added advantage of providing lateral support to wheel traffic during harvesting and transport operations. Infiltration tests confirm preferential water flow sideways, reducing the risk of significant wetting in the compacted central area.

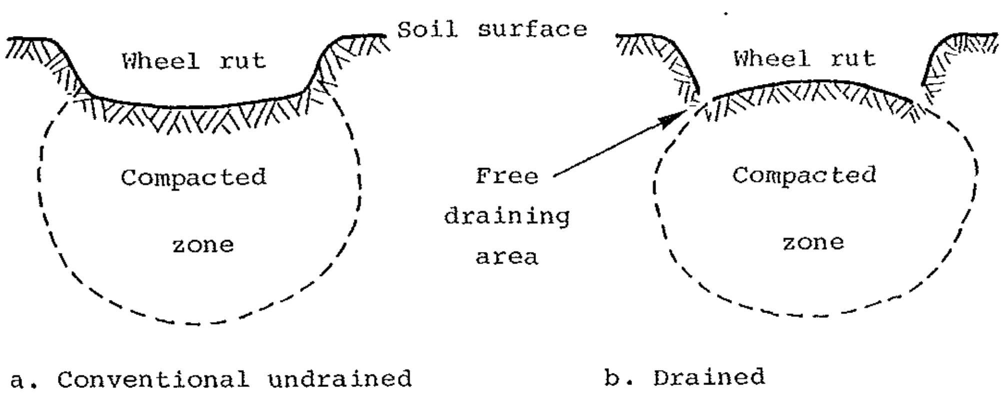

Fig.2, Traffic lane profiles.

Equipment, similar to that shown in Figure 3, is currently being developed to transform the standard wheel rut into the more satisfactory drained profile. The sideways inclined tines shatter the compacted soil at the side of the rut, providing a lateral drainage channel and the angled blades move soil into the centre to camber the base. The loosened soil moved into the centre requires immediate compaction, to avoid the risk of slurry conditions developing in the event of an unexpected rainfall. To-date it has been possible to achieve a flat bottomed rut with side drainage; current tyre sections unfortunately tend to negate the desired cambered profile. Drainage has however, proved satisfactory with this profile.

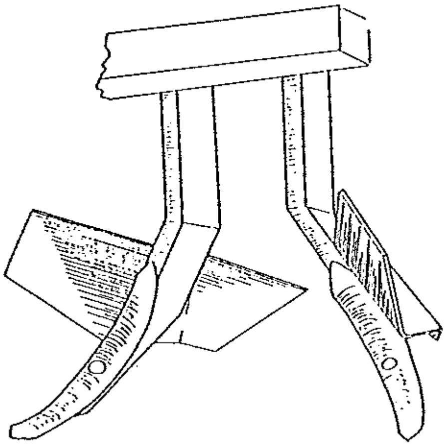

Fig.3, Traffic lane former.

CONCLUSIONS

Controlled traffic systems offer the opportunity to advance sugar beet drilling following wet periods, reduce harvester and trailer rolling resistance and provide more favourable growing conditions to enable more efficient beet lifting at harvest. Drained traffic lanes are required to maximise the benefits from the system.

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CONTROLLED TRAFFIC IN SUB-TROPICAL GRAIN PRODUCTION

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INTRODUCTION

Data collected during tractor performance surveys (Tullberg and Murray 1987) can be used to show that the mean drawbar energy requirement of common tillage implements was between 25MJ.ha^{-1} for a cultivator and 65MJ.ha^{-1} for a chisel plough. Mean tractive efficiencies were 69% for 2WD and 75% for 4WD tractors working in the extensive grain growing areas of S.E. Queensland, where the predominant soil type is a heavy black vertisol.

At these levels of energy input and efficiency, between 8.3MJ.ha^{-1} and 29.2 MJ.ha^{-1} is being dissipated in the soil/tyre interface. This energy must be absorbed largely in plastic deformation of the soil.

Deformation and bulk densely increase within the tilled layer appears likely to increase the energy requirement of the implement (Bateman et al 1965), while the same process in the sub-tillage layer is usually regarded as compaction. Arndt and Rose (1966) noted this effect in the context of tillage and traffic.

In controlled traffic cropping all tractor and implement wheels are set to the same track width and run on defined "roadbeds", while all crop growth occurs in the intervening "rootbeds". This avoids the energy loss and soil damage incurred in repeated compaction and tillage of the wheeltracks. A major objective of recent work at QAC has been to assess the effect of controlled traffic operation on tractor energy losses and tillage energy requirements, as well as soil and crop effects.

METHODS

Tractor and implement energy inputs, crop yields and soil condition were monitored in two groups of replicated small plots, (each of 16 x 0.1 ha), and two large demonstration plots (each of 2 x 4 ha) over three years. Cropping generally followed that of adjacent production areas, with barley as the major winter crop. Summer crops of sorghum and soybeans were each grown on one occasion.

The tractor used was a 103kW (pto) equal wheel 4WD (Mercedes MB-1500). It was instrumented to allow measurement of fuel flow, drawbar pull, ground speed and wheel slip, and operated on 18.4 x 34 tyres at a track width of 2.85m.

A heavy chisel plough and cultivator/air seeder were also modified to operate on 2.85m roadbeds. These had working widths of 5.7m and 8.55m respectively, and could be set to till out their own wheel tracks in conventional plots, or leave the roadbeds untilled in controlled traffic.

Both were fitted with ultrasonic depth monitoring units in an attempt to ensure that all controlled traffic and conventional operations were carried out at the same depth. Some conventional plots were deep-tilled (to 300 mm) annually.

Harvesting was carried out using a 6.2m cut combine with 2.9m track width and 24.5 x 32 tyres.

RESULTS AND DISCUSSION

Implement Draft

Overall mean implement draft figures are set out in table 1. Controlled traffic reduced the mean draft of the chisel plough by 41% in primary tillage using50mm chisel points and by 30% when the same implement was used with 0.45m sweeps at smaller depth. In initial tests with the cultivator the mean reduction in draft was only 14%, and non-significant. This appeared inconsistent with the reduction in soil-engaging width of > 16% in controlled traffic operation.

Draft measurement with the cultivator lifted out of work also demonstrated that operation on roadbeds could reduce the rolling resistance of this 2.5t machine by 2kN. If draft per tine was similar in conventional and controlled traffic operation, these considerations indicate a draft reduction of approximately 25%.

The general arrangement of this machine with support wheels in front of the tines, combined with a very flexible frame, appeared to provide an element of 'draft control'. At the same time the heavy damping of the ultrasonic depth monitor, combined with the positioning of the transducers ahead of the frame, reduced the ability to detect depth change.

In subsequent tests, with greater attention to depth monitoring, the treatment effect increased to 24%. If draft/tine is reduced in controlled traffic this must be an understatement, reflecting continuing depth control problems. Modification to avoid this problem was difficult when the unit was intended for use in controlled traffic and conventional systems.

Table 1. Controlled Traffic Effect on Draft

	Conventional kN	C. Traffic kN	5% LSD kN	Reduction %
Chisel + points	23.3	13.7	2.2	41
Chisel + sweeps	24.9	17.6	3.1	30
Cultivator-initial	23.2	19.9	N.S	14
Subsequent	24.7	18.8	2.4	24

Each figure is the mean of at least 5 (runs) x 8 (plots) x 3 (operations).

Tractive Efficiency

Tractive efficiency was measured on many occasions during this work, and values are illustrated in the efficiency: slip curves of figure 1. Maximum efficiency values of about 83% at 10% slip and 75% at 12% slip in controlled traffic and conventional tillage respectively coincide with the values which might be expected for a 4WD tractor operating on firm and tilled soil conditions.

Most of the improvement in 4WD tractive efficiency could be attributed to the reduction in the mean coefficient of rolling resistance from 8.4% on conventionally tilled plots to 5.8% on controlled traffic roadbeds. Separate and less extensive tests with a 2WD tractor indicated that operation on roadbeds would improve tractive efficiency from 65% to 78% again corresponding to the difference between tilled and firm soil (Zoz 1970).

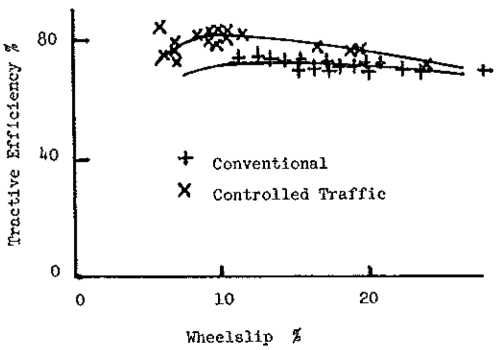

Figure 1 Tractor Performance

Soil and Crop

Controlled traffic apparently had little effect on soil bulk density, and the effect on cone penetrometer force/depth characteristics was not great. The most notable effect of controlled traffic was on water infiltration rate, as determined by double-ring infiltrometer. These results are set out in table 2, which shows that infiltration was substantially greater and more uniform in controlled traffic plots.

Table 2 Infiltration Data

Treatment	Infiltration Rate Equation mm/hr	Cumulative Infiltration* mm in 1.66 h	Coeff. of Variation %
Controlled Traffic	451 T e-0.195	848	31
Conventional	64 T e-0.35	140	72
Conventional Deep Tilled	251 T e-0.20	446	38

T = Time from water application, h. * 1% LSD = 270 mm.

Despite some evidence of a small yield loss in the first year of cereal cropping, the cumulative total yield from all controlled traffic plots was the same as that from all conventional crops at the end of this study. Yield transects sometimes showed considerably greater yield in the rows adjacent to the roadbeds. Variability in this effect was clear evidence of inaccurate tractor/implement guidance, which was the most important single difficulty encountered during this work.

Energy

The combined effects of reduced implement draft and improved tractive efficiency is a reduction in the tractor energy input by between 51% (2WD with chisel) and 31% (4WD with cultivator). These data indicate that controlled traffic operation would reduce the energy requirement of this sequence of three operations by 38% (4WD) and 40% (2WD).

This statement of the energy effects implies no change in tillage requirements under controlled traffic. Factors such as the large increase in infiltration suggest that controlled traffic would at least eliminate the requirement for deep tillage. This appears to be an increasingly common requirement of both "zero tillage" and conventional cropping practice.

The statement is also conservative because problems of experimental technique tended to increase controlled traffic energy requirements, and be difficult to correct rapidly in a small plot. This can be illustrated with reference to the depth control problems mentioned earlier, and to the difficulty of aligning tractor/implement combinations accurately with the roadbeds. Use of the same tractor tyre equipment, and implement wheel spacing in controlled traffic and conventional operation also reduce the energy effect.

CONCLUSION

Many areas of uncertainty remain, but the results demonstrated that controlled traffic operation can potentially:

(i) reduce the fuel cost of crop establishment by at least 40%.

(ii) allow similar output and capacity from a tractor of at least 30% less power,

(iii) maintain yield without the necessity for deep tillage operations, and

(iv) increase rainfall infiltration and so reduce run-off and erosion in some circumstances.

Controlled traffic can provide great economic benefits in extensive dryland grain production systems, but it does demand improved tractor/implement guidance. Where farming systems already demand accurate tractor guidance (e.g. furrow-irrigated row crops) these benefits have already been achieved by a small number of innovative farmers. Future work must demonstrate that this can also be achieved in the broadacre situation.

ACKNOWLEDGEMENT

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PERSPECTIVE OF REDUCING SOIL COMPACTION BY USING A LOW GROUND PRESSURE FARMING SYSTEM; SELECTION OF WHEEL EQUIPMENT

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ABSTRACT

Criteria are presented that were used for the selection of wheel equipment for an experiment concerned with reducing soil compaction by using a "Low Ground Pressure Farming System (LGP)". Mainly tyre width and inflation pressure were adapted to reach an acceptable level of soil-tyre contact pressure. This adaption procedure is applied to machinery that would suit a 60 ha. arable farm with a rotation of ware potatoes, onions, winter-wheat and sugar-beets. The LGP-system is used as one of the traffic treatments in the experiment, next to a "High Ground Pressure Farming System (HGP)", representing agricultural practice, and (an earlier investigated) "Zero-traffic (ZGP)" treatment.

INTRODUCTION

Previous research on controlled traffic in the Netherlands has shown that uncontrolled, intensive field traffic can induce a sub-optimal soil-structure in the tilled layer as well as in the sub-soil (Lamers et al, 1986). Compared to "Zero-traffic", yield reductions occurred up to 10% on a hectare basis. However, on the average, the better production on the non trafficked zones could not compensate for the losses due to the not cropped permanent traffic lanes. The traffic-lane system also appeared to be costly to realize especially as far as root crops are concerned. Another result of this research is that sugar-beets, being a very important crop in the Netherlands, appeared to respond well to a slight (0.6 bar) precompaction.

In economical sense, a conventional system adapted to apply a low level of pressure on the ground seems to offer better opportunities to avoid compaction in the Netherlands. Research on the perspective of a low ground pressure farming system started in 1984 as part of a four year joint research project between Germany, UK and the Netherlands on methods to avoid soil physical degradation. This project is supported financially by the Land and Water Use and Management programme of the European Commission. In the Netherlands, six agricultural research institutions collaborate to study the complex relationship between ground pressure, soil compaction and plant growth.

It was decided to concentrate our research work on the application of a Low Ground Pressure Farming System (LGP) in the Netherlands. For this purpose, a 10 ha. field trial was layed out in 1984 in which a LGP-system is compared to a farming system having relevance to the present field traffic situation (HGP). As a reference a zero traffic (ZGP) system is also included in the experiment. The same equipment is used in the LGP- and the HGP-system but with different wheel equipment.

The tractor and machinery inventory would be relevant to a 60 ha. arable farm. In this poster-paper, the basis for selection of wheel equipment in the experiment is presented and examples of adaptions are given.

TRAFFIC TREATMENTS IN THE EXPERIMENT

The Dutch farming system for medium to heavy soil includes ploughing in the autumn and seedbed preparation in spring. In this system, wheel traffic can have two main effects:

1. Seasonal effects
   - wheelpasses on tilled soil can increase soil density to a level where plant growth is impeded directly, mainly by lack of aeration or high mechanical resistance
   - wheel ruts in spring can prohibit the preparation of a good seedbed of uniform depth
2. Long term effects
   - soil deformation by wheelpasses in wet soil conditions may cause smearing (loss of soil structure). The annual tillage operations and wheathering effects may not be able to alleviate this effect and an overall deteriorated soil structure in the tilled layer may be the result
   - The subsoil may be compacted or smeared by (heavy) wheel traffic. This effect is not alleviated by yearly tillage operations and can therefore impede plant growth by reduced permeability for water and roots

In vieuw of the choise of wheel equipment for agricultural tractors and machinery, one ultimately has to formulate the soil requirements from an agronomic point of view. The relations between soil structure and plant growth on the one hand and soil structure change and way of loading on the other hand are very complex. The present knowledge does not yet allow to formulate a straightforward path for translating criteria for undisturbed growth to f.i. allowable pressure levels.

Low Ground Pressure Farming system

For the LGP-experiment,it was decided to use fixed levels of average pressure in the tyre-soil contact-area in conjunction with the seasonal and long term effects. From experience and supporting evidence in former controlled traffic research, the pressure levels were choosen in such a way that no adverse effects from traffication are expected:

- in spring, before sowing, average tyre-soil contact of of uncontrolled traffic should not exceed 50 kPa. Both direct compaction effects and deep rut formation in spring would thus be avoided at normal field conditions in spring.
- as an overall measure, the average tyre-soil contact pressure never exceeds 100 kPa to avoid long term deterioration of soil structure

It should be noted that as far as soil response is concerned, average tyre-soil contact pressures of 50 and 100 kPa would be equivalent to higher pressure levels in an uniaxial compression test. Multiplication factors in the range of 2 - 4 are mentioned for the combined effect of uneven stress distribution and shear stresses in the contact area (Koolen and Kuipers, 1983).

Table 1. Average tyre-soil contact pressure (Pc) and inflation pressure levels (Pi) applied in the experiment (in kPa).

	HGP		LGP	
	Pc	Pi	Pc	Pi
Uncontrolled traffic				
before sowing/planting	100	80	50	40
other operations (tractors,combine)	200	160	100	80
trailer- and implement tyres	300	240	100	80

High Ground Pressure Farming system

The HGP-system is intended to have relevance to agricultural practice. This was done by estimating the usual average tyre-soil contact pressures with commonly used wheel equipment and inflation pressures. In spring, before sowing, farmers are cautious with the loose soil and often apply dual wheel equipment. It was estimated, that tyre-soil contact pressures would amount to 100 kPa. During the season, the usual tractor-tyre inflation pressure is 160 kPa, while for the trailers and implements 240 kPa would be a good estimate. This would be equivalent to 200 and 300 kPa tyre-soil contact pressure resp.

Zero traffic

In the ZGP-system, it is obviously not intended to exert any pressure on the soil. The equipment to create 2.5 m wide, not trafficked cropping strips is available from previous controlled traffic research at IMAG.

A summary of choosen average tyre-soil contact pressures is given in table 1.

SELECTION OF WHEEL EQUIPMENT

The technical possibilities to achieve a certain average soil-tyre contact pressure with regular agricultural tyres at a fixed tyre load are the following:

- selection of tyre inflation pressure.
  Inflation pressure will only influence the av. soil-tyre contact pressure as long as the tyre operates in its deflected range. Lower inflation pressure will then result in a larger contact area and thus give a lower average soil-tyre contact pressure. Perdok (1978) illustrates this behaviour for a wheel load of 25 kN applied to regular agricultural tyres in a width range of 0.3 - 0.5 m. (see fig 1.) The deformation factor c in fig 1. stands for the ratio of the (larger) diameter of a rigid wheel that would behave similar to the deflecting tyre and the nominal diameter of the tyre under consideration. A c-factor with value 1 means that the tyre behaves like a rigid wheel. It can be seen, that deflection behaviour is different for soft soil (ploughed) and firm soil (stubble). For rigid wheels, the average wheel- soil contact pressure largely looses its meaning.

- selection of tyre width.
  Once the load and inflation pressure are fixed, the tyre width can selected in such a way that max. allowable deflection occurs. The choise of a wider tyre would only be appropriate if we whish to increase the load or decrease the inflation pressure.

- selection of tyre diameter.
  A bigger diameter will give us an increase of contact length and thus a lower average tyre-soil contact pressure. Deflection behaviour is in general not much affected by tyre diameter for tyres with a normal ratio of section height to width (appr. 0.8) Substantial changes in tyre diameter will often result in radical constructional adaptions of the machinery. This option was not considered for experimental purposes therefore.

When the above possibilities to achieve a certain average wheel-soil contact pressure are exhausted or not feasible, the load per wheel should be lowered, either by applying more wheels (tandem or dual) or by decreasing the load of the machinery itself.

For the selection of wheel equipment in the experiment, the options inflation pressure and tyre width were used with priority. To ensure that the intended average tyre-soil contact pressures mentioned above will occur in the experiment, the tyres were selected for operation at approximately their max. allowable deflection, both for the LGP- and the HGP-system. Under this conditions, the following relationship between average tyre-soil contact pressure Pc and tyre inflation pressure Pi was assumed:

$$Pc = 1.25 \times Pi$$

This also means that the applied inflation pressures in the experiment are fixed for the selected contact pressure treatments (see tabel 1)

Knowing that the load on tyres can vary considerably for the different operation modes of tractors and implements, typical loading conditions were selected for the field- and the road situation for groups of field operations. Tyres were selected in first instance for the field situation. Use was made of the empirical formula's of Perdok and Arts (1986, 1987), representing the data of manufacturers on loading capacity (Wp) at certain inflation pressure (Pi) for different tyre width (B) in a general form. The formula's are valid for a speed of 30 km/hr.

$$\text{for } B < 0.5 \text{ m} \quad : \quad Wp = (1 + 100\, B^2).(0.01\, Pi)^{0.585}$$

$$\text{for } B > 0.5 \text{ m} \quad : \quad Wp = (1 + 50.B).(0.01\, Pi)^{0.585}$$

Wp in kN; B in meter; Pi in kPa.

A graphic representation of these formula's is given in fig. 2 for inflation pressure levels of 40, 80, 160 and 240 kPa.

In most cases, this procedure yielded an acceptable solution, also for the road situation, where the possibility exists to apply higher inflation pressures. As an example, the tyre selection for the tractor rear axle during harrowing in spring is taken. With a (maximum) weight

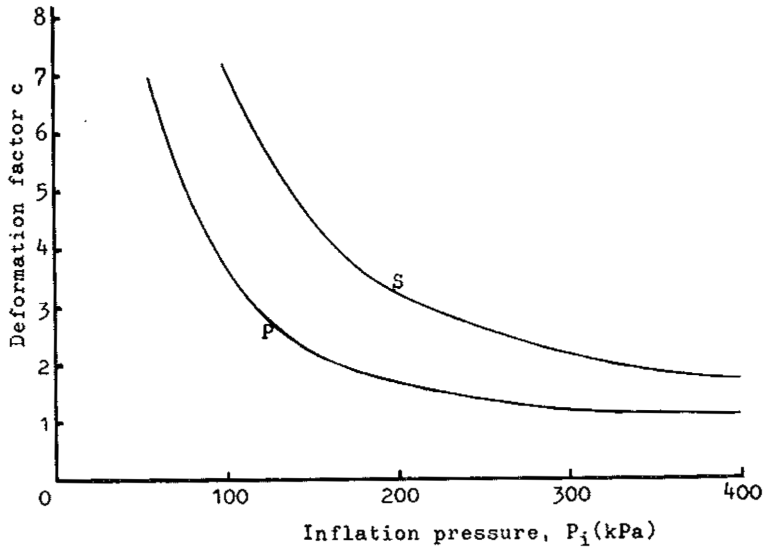

Fig. 1: Relationship between deformation factor c and tyre inflation pressure P_i for fields P, ploughed and S, stubble at wheel load of 25 kN.

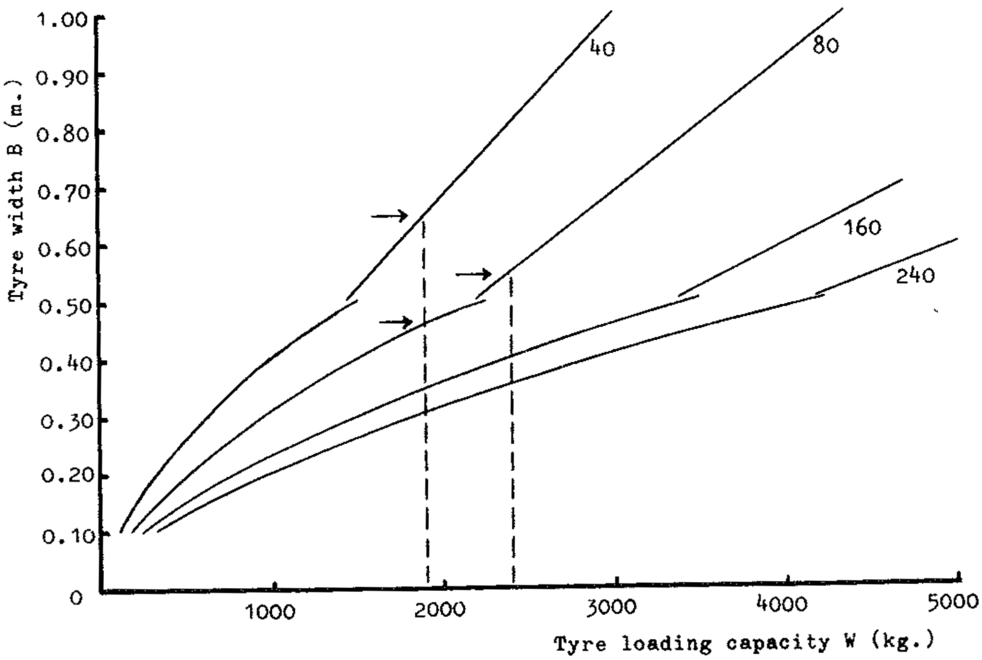

Fig. 2: Relationship between tyre width and loading capacity for agricultural tyres according to Perdok and Arts (1986).

transfer of 1500 kg to the rear axle, the typical rear axle load is 3600 kg. From fig. 2 one can see that for a loading capacity of 1900 kg tyres of 0.65 m wide are needed for the LGP-system (40 kPa) and tyres of 0.47 m wide for the HGP-system (80 kPa). Tyre sizes 650-38 and 18.4-38 were therefore selected.

The 10 tons trailers have been equipped with a steered tandem because at 80 kPa inflation pressure the lateral deformation of the tyres during turning would otherwise damage the tyres. The load on each tyre when fully loaded will amount to 2400 kg (maximum) in the field. From fig. 2, one can see that tyres of 0.53 m wide are needed. The closest choise was therefore 20" tyres for the LGP-system.

CLOSING REMARKS

The machinery for a 60 ha arable farm, using a 82 kW and a 55kW tractor, is adapted for Low Ground Pressure for experimental purposes. The maximum load on a single axle appears to stay below 8000 kg. The adaptions are all directly applicable in practice with an exception for mouldboard ploughing with the 82 kW tractor, for which we still have to develop a better solution than the one used in the experiment.

For machinery smaller in size, achieving lowered tyre-soil contact pressures by the application of wider tyres and lower inflation pressures would be easier to realize. The standardized distances between crop rows and the restricted width of the furrow during mouldboard ploughing will not be a constraint for wider tyres here. Similarly, restricted row distance and furrow width will certainly be a constraint for heavier machinery.

Especially for harvesting operations, Dutch farmers often make use of cooperatively owned machinery or hire the job out to a contractor. This is generally large scale, heavy machinery with loads per axle even up to 16 tonnes. Research is necessary to check whether the assumption that an average tyre-soil contact pressure of 100 kPa will not damage the soil structure at normal field conditions, can also be made for these high total axle loads.

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MAIZE GROWTH AND YIELD AS AFFECTED BY SUBSOIL COMPACTION AND DEEP TILLAGE

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ABSTRACT

Wheel traffic from axle loads in excess of 4.5 Mg increased bulk density to a depth of 60 cm on a clay loam soil in Minnesota. This one-time application of high axle loads caused corn (Zea mays L.) yields to be initially decreased 9-27%. Yields gradually returned to normal over a period of 3-5 years. Subsoil tillage to depths of 35-51 cm loosened the soil but did not significantly affect the yield of corn.

INTRODUCTION

Historically, most of the soil compaction research in the United States has been concerned with excessive compaction within the tilled layer (0-30 cm), or at the bottom of the tilled layer (tillage pans and/or traffic pans). This was because most farm machinery, until recent decades, weighed less than 5 Mg, and theory emphasized specific pressure on the soil surface (opposed to total load) as being the main factor determining soil compaction from wheel traffic of agricultural machinery. More recently, compaction deeper than normal tillage was found to persist under field conditions as a result of wheel traffic from agricultural machinery with axle loads in excess of 5 Mg, even though pressures on the soil surface were not excessive (Blake et al., 1976; Danfors, 1974; Eriksson, 1976).

The documentation of subsoil compaction, often with detrimental effects on crop yield (Eriksson et al., 1974), and the ever-increasing weight of farm machinery, prompted the formation in 1980 of an International Working Group on SubSoil Compaction from High Axle Loads. The objectives of this Working Group were to (i) determine the effect of high axle loads on the extent and persistence of subsoil compaction over a range of soil and climatic conditions, and (ii) determine the effect of subsoil compaction on growth and yield of several crops (Anonymous, 1980). Results from at least 3 years of field data from all locations were recently summarized, showing a general detrimental effect of subsoil compaction on crop yield that persisted for a number of years (Hakansson et al., 1988).

The inability of natural weathering forces to alleviate subsoil compaction in one year's time necessitates re-evaluation of other means of subsoil amelioration. The most obvious means is deep tillage or subsoiling. While there has been extensive research on deep tillage, the results have not been conclusive with respect to increasing crop yield. The reasons for this lack of consistent positive yield response may be insufficient depth of tillage, re-compaction of loosened soil by subsequent wheel traffic, or an actual deterioration of some soil property by the deep tillage operation.

The objectives of this paper are to (i) briefly summarize the soil and corn (Zea mays L.) yield response from one recently completed field study on the High Axle Load Working Group, and (ii) report on progress in a new field study evaluating the effectiveness of various tillage depths to alleviate subsoil compaction, and the resulting corn yield response.

METHODS

The high axle load field study was initiated in the fall of 1981 on a Webster clay loam (fine-loamy, mixed, mesic, Typic Haplaquoll) at the Southern Experiment Station, Waseca, Minnesota, USA. The soil has about 33, 29, and 38% sand, silt, and clay, respectively. This soil has adequate surface drainage but is classified as being somewhat poorly drained internally, and is tiled. Immediately prior to initiation of the experiment, the site was cropped to oats (Avena sativa L.), and before that, several years of row crops. A split-plot design was used with four replications. Detailed description of the compaction treatments was previously reported (Voorhees et al., 1986). Soil water content at the time of compaction treatment application was 80-90% of field capacity. Briefly, the compaction consisted of covering the entire plot surface with wheel traffic of 9 and 18 Mg/axle vehicles, typical of harvesting equipment in the United States. A check treatment received no heavy wheel traffic. The entire plot area was moldboard plowed to about 25 cm after applying the high axle load treatments. For the following 5 years all wheel traffic was controlled to certain traffic lanes and did not exceed an axle load of 4.5 Mg, thereby leaving some plots void of any wheel traffic compaction in the surface 25 cm, but having various levels of subsoil compaction. After the initial moldboard plowing in the fall of 1981, these plots received no fall tillage, only spring tandem disking before planting. Corn and soybeans (Glycine max. L.) were grown in rotation with both crops planted each year. Plant sampling and crop yields were determined in plots that had no surface layer compaction.

The subsoiling experiment was initiated the fall of 1986, again on a Webster clay loam but at a different site. An established alfalfa (Medicago sativa L.) crop was chemically killed in late summer, and the surface 7-8 cm disked prior to applying wheel traffic from a 21 Mg/axle load. The entire plot surface was covered with heavy wheel traffic. Check treatments received no heavy wheel traffic. All subsequent field operations were conducted with axle loads less than 4.5 Mg, controlled so that plots were void of surface layer wheel-induced soil compaction. Unlike the prior experiment, this study will have high axle load wheel traffic applied each fall for a number of years to test accumulation of subsoil compaction. The field experimental design was a split-plot with four replications, with the two subsoil compaction treatments as the main plots. The split-plots consisted of two subsoil tillages with a parabolic chisel point to 35 and 51 cm. The shanks were spaced 76 cm apart, and were set to run midway between 76 cm spaced rows. Three chisel points were pulled with each pass and tilled the width of the tractor, to prevent re-compaction by the tractor wheel of soil loosened by the subsoiling operation. In addition to the subsoiling treatments, there was a control treatment consisting of chisel plowing to about

20 cm. Bulk density and soil water content were determined from 4.76 cm diameter undisturbed cores at various depth increments before and after passage of the high axle load wheel traffic. At least 8 cores were sampled per treatment. Penetrometer resistance was measured with a Bush recording penetrometer interfaced to a Polycorder data storage unit (Wagner et al., 1988). These data were taken before and after high axle load wheel traffic in the fall, and again the following spring. Corn and soybeans are grown in rotation with each crop grown each year. Plant data were collected from plots that did not have surface layer compaction.

RESULTS AND DISCUSSION

In the first experiment, axle loads of 9 and 18 Mg significantly increased the bulk density over the 4.5 Mg axle load to depths of about 35 and 60 cm, respectively. Consequently, hydraulic conductivity of the soil was decreased. This change in internal drainage characteristics persisted over winter in spite of soil freezing to depths of 70 cm. Corn yield, expressed as yield relative to the 4.5 Mg/axle treatment, is shown in Figure 1 for the 5-year duration of the experiment. Corn yield was initially decreased 9 and 27% by the 9 and 18 Mg/axle treatments, respectively. With the given set of climatic conditions over the 5-year period, corn yields were adversely affected by the one-time application of high axle loads for 3-5 years. Corn height and dry matter accumulation showed a similar response over time. A different 5-year climatic regime would probably have altered the time for natural amelioration of subsoil compaction. A more detailed discussion of the results of this completed experiment is found in Voorhees et al. (1986) and Voorhees et al. (1988).

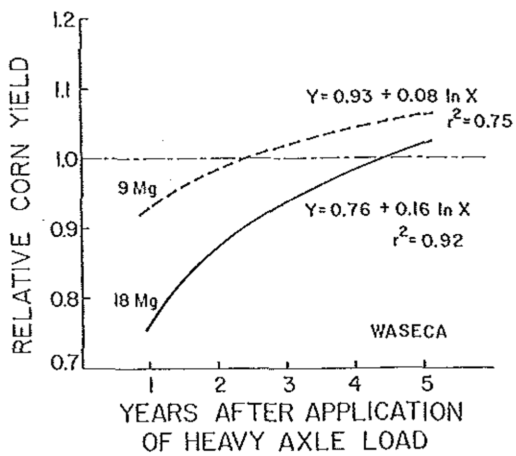

Figure 1. Relative corn yield over time as affected by high axle load.

The subsoiling experiment, sequel to the above results, is still in progress but the first year's results are of interest. Figure 2 shows the bulk density and penetrometer resistance profiles before and after application of the 21 Mg/axle treatment. Neither showed any significant response to the high axle load. There was, however, a consistent trend for subsoil bulk density to be higher after high axle load wheel traffic than before. There are several possible reasons for this. The soil was at or very near field capacity water content throughout the profile. This, in combination with a relatively high initial bulk density and a stable soil structure from several prior years in alfalfa, may have precluded any large change in bulk density with the given load.

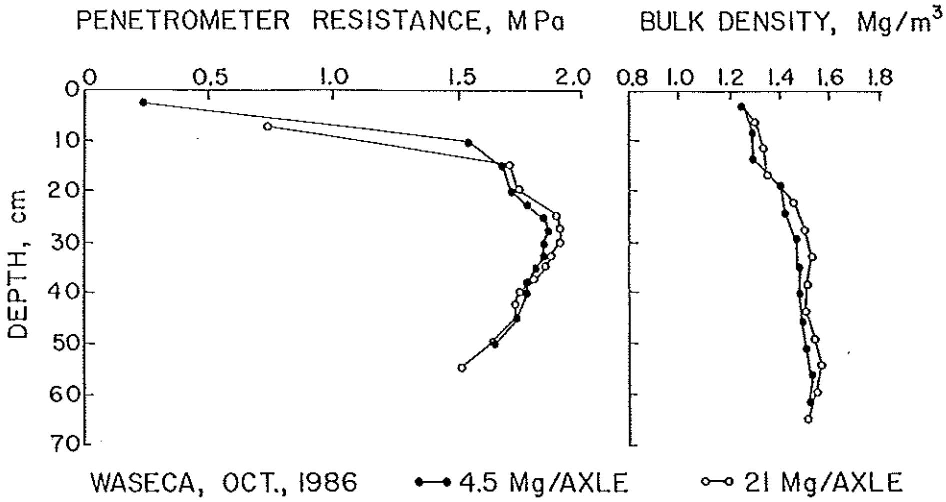

Figure 2. Penetrometer resistance and bulk density before and after 21 mg/axle load wheel traffic.

The subsoiling operations were also performed under relatively wet conditions. The extent to which the subsoiling treatments loosened the soil was assessed by measuring penetrometer resistance in a grid perpendicular to the subsoiling slot. Figure 3 shows isolines of equal penetrometer resistance across two adjacent subsoiling passes for the two depths of subsoiling and for the compacted and noncompacted treatments. There was very little difference in the shattering patterns between the compacted and noncompacted treatments when they were subsoiled to 35 cm. Subsoiling to 51 cm, however, caused considerably less lateral shattering in the compacted plots than in the noncompacted plots. Despite the lack of bulk density and penetrometer resistance differences between the compaction treatments, the treatments responded differently to the subsequent subsoil tillage.

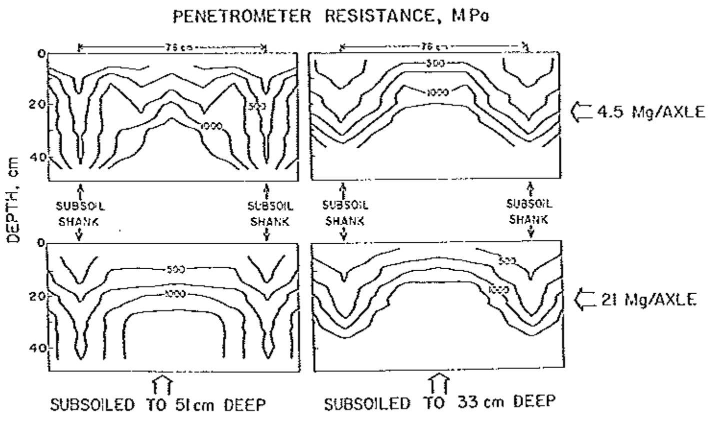

Figure 3. Penetrometer resistance isolines as affected by high axle load and subsoil tillage.

Figure 4 shows penetrometer resistance in the subsoiling slot immediately after fall subsoiling (left), and in the spring (right) after over-winter settling. All treatments had slightly higher resistance values in the spring, but the deep subsoiling treatment (51 cm) showed the largest increase from fall to spring. This is probably re-bounding of soil compacted laterally by the subsoiler shank passing through wet compacted soil (see Figure 3). There were no differences in water content among treatments.

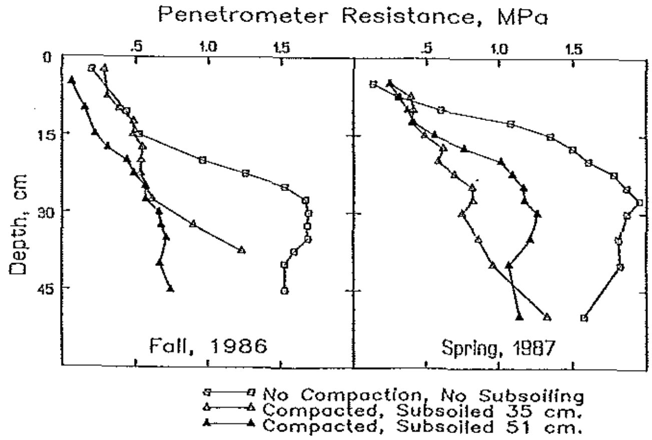

Figure 4. Penetrometer resistance in subsoiled slot.

The first year yield results are reported in Table 1. The yields on all treatments were excellent due to a very favorable growing season for corn. There were no compaction or tillage depth effects on yield. The combination of wet conditions at the time of compaction and deep tillage and the ideal growing season minimized the effect of either compaction or tillage.

Table I. Corn grain yield as affected by high axle load and subsoil tillage. 1987.

	Depth of Tillage, cm		
Axle load (Mg)	20 (kg/ha)	35 (kg/ha)	51 (ka/ha)
<4.5	11,424	11,668	11,575
21	12,020	11,371	12,203

Collectively, the above data illustrate the complexity of subsoil compaction and attempts to effectively alleviate it. Given the right soil water content, axle loads of 9 and 18 Mg can cause subsoil compaction that will significantly decrease corn yield for a number of years. However, these axle loads may not cause significant increase in subsoil bulk density if the soil is near field capacity at time of traffic and the soil has a relatively stable structure.

The ability of deep tillage to ameliorate subsoil appears to depend on soil water content and the degree to which the subsoil is compacted. Even though bulk density measurements did not indicate much change in subsoil structure due to high axle load wheel traffic, there was definitely some physical change as evidenced by the shattering patterns. Crop yields in response to either heavy wheel traffic or subsoil tillage is dependent on climatic conditions and may be evident only when growing season conditions are less than ideal.

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SECTION 3

MODELLING THE SOIL/MACHINE/PLANT SYSTEM

AN EVALUATION OF EMPIRICAL ROOT GROWTH MODELS TO DESCRIBE ROOT DISTRIBUTION IN COMPACTED SANDY SOILS

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ABSTRACT

Tillage induced subsoil compaction occurs commonly on structureless to weakly structured fine sandy soils. The presence of subsoil compaction is defined as a degree of compaction exceeding 0,7. Degree of compaction was defined as the ratio between actual minus the minimum the bulk density of a soil layer and the difference between maximum and minimum bulk density.

Subsoil compaction impedes deep rooting to a certain extent and promotes rooting in the topsoil. This leads to a sharp decrease in rooting density with depth.

Two empirical root distribution models obtained from literature were used to describe the change in rooting density with depth. Both models could be applied under compacted conditions for wheat, peanuts and cotton. It was necessary to modify one of the equations for maize and peas, for which the modified model was most suitable.

INTRODUCTION

Any simulation model for water and/or nutrient uptake from different soil layers requires change in rooting density, with time and depth, as an input variable. As discussed by Taylor (1983) in an overview, the root distribution pattern with depth is affected by many internal and external soil and plant factors, several of which can be manipulated by soil and water management. One of these factors is the mechanical impedance of the soil to root growth or penetrometer resistance which is a function of bulk density and water content for a specific soil horizon or layer (Bennie and Burger, 1988).

The fine sandy apedal soils, of which large areas are cropped in Southern Africa, are very susceptible to compaction when cultivated. Causes for this compaction susceptibility and its adverse effects on plant growth have been discussed in detail by Bennie and Krynauw (1985) and Bennie and Botha (1986). The most important external factor causing soil compaction is mechanically applied forces, the primary source being vehicular traffic during soil cultivation.

A compacted layer just below the topsoil largely restricts root development to the topsoil, resulting in a sharper decrease in root length density with depth compared to less compacted soils. This phenomenon was clearly demonstrated by Bennie and Botha (1986).

A root growth model can become very complex and the degree of sophistication will be determined by the extent to which the more than

20 major variables affecting root growth, are incorporated. The simplest models are empirical, using mathematical and statistical distribution equations. The objective was to find a model to describe rooting density with depth and time in structureless soils with or without subsoil compaction. Not all the input data required for various models, for example those used by Hackett and Rose (1972), Lungley (1973), Bartos and Jameson (1974), Hillel and Talpaz (1976), Huck and Hillel (1983), Weir et al. (1984), Porter et al. (1986) and Logsdon et al. (1987) were available. Therefore only the models of Gerwitz and Page (1974), Page and Gerwitz (1974) and Rowse and Barnes (1979) could be employed for purposes of evaluation.

In a preliminary investigation the diffusion type model proposed by Page and Gerwitz (1974) yielded unacceptably poor results. Finally, therefore, only the equations used by Gerwitz and Page (1974) and Rowse and Barnes (1979) were compared.

METHODS

Rooting density at 300 mm depth intervals was measured approximately every 20 days during the growing season for wheat (13), maize (8), peas (3), cotton (6) and peanuts (4), on different soil types. The number of sites indicated in brackets. The rooting density sampling was done in trenches, 2 m long, 0,5 m wide and 2,2 m deep. Duplicate soil cores of 1000 cm^3 each were sampled every 300 mm depth. The roots were separated from the soil by washing, the debris removed by hand and the root length determined with an infrared root length counter, the design of which was after Rowse and Phillips (1974), but with several improvements.

The in situ bulk density for each 300 mm depth interval at all the sites was determined with a clod method (Blake, 1965), as well as the maximum Proctor density (Felt, 1965) and the minimum density. Minimum density was determined by pouring dry sieved (<2 mm) soil through a funnel into a 200 cm^3 cylinder with a 50 mm diameter. The mass of soil was determined after excess soil was scraped off. The degree of compaction for each layer was calculated as follows:
Degree of compaction = (bulk density - minimum density)/(maximum - minimum density). The following unpublished compaction classes were previously derived by the authors and were used to evaluate root impeding characteristics of compacted soil layers.

$<$0,5 - Low degree of compaction
0,5 - 0,6 - Medium degree of compaction
0,6 - 0,7 - High degree of compaction
$>$0,7 - Very high degree of compaction

Measured total root length per unit land surface (L, mm $root.mm^{-2}$ soil surface) and depth (Z, mm), within which 90% of L was found, were used to estimate the rooting density (Lv, mm $root.mm^{-3}$ soil) for every soil layer (i) at each of the different sites and measuring days. This was calculated with equations 1 (Rowse and Barnes, 1979), 2 and 3 (Gerwitz and Page, 1974).

$$Lv_i = (L^{1/2}/m).\exp\left[-Z_i/(m.L^{1/2})\right] \quad (1)$$

$$P_i = 100\left[1 - \exp(-f.Z_i)\right] \quad (2)$$

or $$Lv_i = L.\left[(1 - \exp(-f.Z_i)) - (1 - \exp(-f.Z_{i-1}))\right]/(Z_i - Z_{i-1}) \quad (3)$$

where P_i = percentage of L at depth Z_i (mm)
$m = Z/(2{,}303.L^{1/2})$
$f = 2{,}303/Z$
Z_i = depth (mm) to the midpoint of layer i (equation 1) or to the lower boundary of layer i (equations 2 and 3).

The accuracy with which equations 1 and 3 describe the rooting density distribution with depth was determined for each of the crops. This was done by means of a linear regression analysis of the estimated Lv against the measured Lv of all the soil layers for the measuring dates for each separate site and for all the sites combined. A 1 : 1 relationship would indicate a perfect fit.

RESULTS AND DISCUSSION

The regression coefficients, Y - intercepts and correlation coefficients, for the combined data, with and without subsoil compaction, are presented in Table I for the different crops.

TABLE I: Linear regression coefficients for estimated against measured rooting densities for the different crops.

Crop	Regression coefficient		Y - intercept		R^2	
	G & P	R & B	G & P	R & B	G & P	R & B
Wheat	0,96	0,97	-0,005	-0,008	0,87	0,89
Peas	0,78	0,74	0,059	0,053	0,90	0,90
	1,02*	-	-0,024*	-	0,94*	-
Cotton	1,04	1,02	-0,021	-0,02	0,62	0,62
Peanuts	0,92	0,91	0,006	0,013	0,76	0,73
Maize	0,75	0,72	0,096	0,094	0,78	0,78
	1,03*	-	-0,036*	-	0,67*	-

* Lv for the compacted sites estimated with the modified equation 4.

It was evident from the results for the individual, as well as all the sites, that both equations gave an accurate description of rooting density distribution with depth and time for wheat, cotton and peanuts in both presence and absence of subsoil compaction. A compaction degree higher than 0,7 in the upper part of the subsoil was considered to have an impeding effect on the normal rooting density distribution. In the case of peas and maize a good agreement between the estimated and measured Lv-values was noted only at sites with no subsoil compaction. At sites with subsoil compaction an underestimation of Lv in the topsoil and an overestimation of Lv in the subsoil were found. This could be corrected by modifying the Gerwitz and Page (1974) model (equation 2) so that the change in percentage of roots with depth is exponentially related to the square root of depth. Equation 3 could therefore be rewritten in the form of:

$$Lv_i = L.\left[(1 - \exp(-f.Z_i^{1/2})) - (1 - \exp(-f.Z^{1/2}_{i-1}))\right]/(Z_i - Z_{i-1}) \quad (4)$$

where $f = 2{,}303/(Z)^{1/2}$

When the rooting density distribution with depth was estimated using equation 4 for those sites with subsoil compaction, good agreement with the measured values was obtained (Table I).

In order to use equations 1, 3 or 4 to estimate rooting density in different soil layers over the growing season, two inputs are required, namely L as a function of time and root distribution coefficients m or f. According to Huck and Hillel (1983) L is mainly a function of the plant canopy development. On the other hand m and f are mainly a function of soil conditions.

From the data collected for this study it was found that the relative depth (RD) in which 90% of L was retained was (0,7 ± 0,02) of the total rooting depth for wheat and for maize, (0,65 ± 0,04), peanuts (0,75 ± 0,02), cotton (0,8 ± 0,02) and peas (0,7 ± 0,05). If the average rooting depth penetration rate (RPR, mm day^{-1}) over the growth period is known, then m and f can be calculated with equations 5 to 7.

$$m_x = (RPR.RD.x)/(2{,}303.L^{1/2}) \quad (5)$$

$$f_x = 2{,}303/(RPR.RD.x) \text{ for equation 3} \quad (6)$$

or $$f_x = 2{,}303/(RPR.RD.x)^{1/2} \text{ for equation 4} \quad (7)$$

where x = day after planting.

To illustrate the applicability of equations 3 and 4 with the relevant f values, calculated with equations 6 or 7 for maize, data of Bennie and Botha (1986) for day 99 after planting were used with the actual measured L and reported RPR values. A good agreement between the measured and estimated Lv values was obtained for compacted and uncompacted treatments (Figure 1).

CONCLUSIONS

The following conclusions can be drawn in terms of the change in rooting density with depth for crops like wheat, maize, peanuts, cotton and peas on structureless to weakly structured soils.

1. The change in rooting density with depth in uncompacted soils can be described accurately with the empirical equations used by Gerwitz and Page (1974) and Rowse and Barnes (1979).

2. In soils with compacted subsurface layers the rooting density distribution of wheat, peanuts and cotton with depth can also be described with both equations. They were not suitable to describe the change in Lv with depth for maize and peas under these conditions.

3. It was possible to modify the equation of Gerwitz and Page (1974)

to successfully describe the change in Lv with depth for maize and peas in the presence of a compacted subsoil layer.

4. It seems possible to apply empirical root growth models to simulate the change in rooting density distribution during the growing season of annual crops.

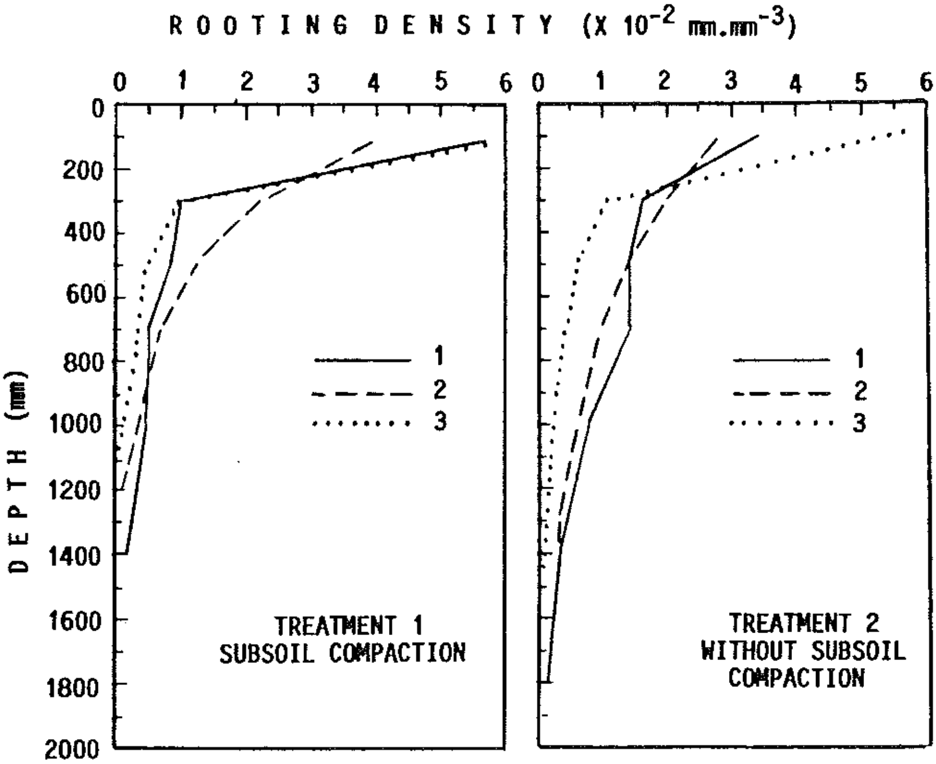

FIGURE 1: Comparison of the actual measured rooting density with the estimated distribution for maize with the original and modified Gerwitz and Page equation (Data after Bennie and Botha, 1986).
1 : Actual measured rooting density
2 : Estimated rooting density with equation 3 (uncompacted)
3 : Estimated rooting density with equation 4 (compacted).

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ELASTO-PLASTIC MODELS FOR AGRICULTURAL SOILS

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ABSTRACT

Undrained triaxial tests were conducted to develop the constitutive relationships for two agricultural soils which could be used in the finite element analysis of soil compaction. Assuming an associated flow rule, an elastic-plastic constitutive model was developed. Simulated data compared fairly well with experimental results, but tended to overpredict at higher stress levels.

INTRODUCTION

Soil compaction is a major concern among farmers because of its many adverse effects associated with it. Reduced root development, low hydraulic conductivity and infiltration rate, reduced nutrient uptake, decreased crop yield, and increased runoff and soil erosion are selected examples of such adverse effects. Many factors such as soil type, moisture content, load rate and magnitude, vehicle type affect soil compaction. Neither the effects of these variables nor the mechanics of soil compaction are well understood. A clear understanding of the mechanics of soil compaction however, is necessary if soil compaction is to be minimized.

A majority of the past studies dealing with soil compaction were experimental in nature and included laboratory as well as field studies (Johnson et al., 1984, Bailey et al., 1984, Burger et al., 1985, Koger et al., 1983). Experimental studies generally are expensive because they are labor intensive and time consuming. Therefore, a study was initiated at Virginia Tech to evaluate the potential use of a finite element (FE) procedure for soil compaction studies. The FE procedure may not answer all soil compaction related questions. However, the FE method jointly with experimental procedures could be used to find solutions to compaction problems faster and more efficiently. A feasibility study conducted earlier indicated that FE method can be used successfully to predict the compaction zone within the soil resulting from a wheel loading and the expansion of this zone due to multiple wheel loading (Pollock, 1983). However, one of the main ingredients needed for the FE analysis is a constitutive relationship or a relationship characterizing the material behavior.

A review of the literature revealed that a constitutive relationship suited for FE analysis of soil-wheel interaction in agricultural soils is still not available. Most models available today are for non-agricultural soils and are based on laboratory test results conducted at low loading rates. Therefore, the overall objective of this study was to develop constitutive relationships for two agricultural soils which could be used in the FE analysis of multipass effects of vehicles on soil compaction.

METHODS

A conventional triaxial cell was used for the laboratory tests. An Instron testing machine (Model 1123) equipped with a 5kN reversible load cell was used to load the sample and to record the load deformation data. A microcomputer based data acquisition system (Apple-II plus) controlled the tests while recording the axial stress and strain data.

Two agricultural soils were selected for this study. One, sand with clay (SC), was supplied by Deere and Company. The second, sand with silt (SM), was from southeastern Virginia. Both soils were classified based on the Unified Soil Classification System. Moisture levels were selected to represent typical field operating conditions. The densities of SC and SM samples were 1.5 and 1.4 gm/cc respectively.

Triaxial tests were conducted at different loading rates for a SC soil in order to determine the influence of loading rate. As in most engineering materials, the strength of the sample increased with increased loading rate. The slowest loading rate (5 mm/min) correspond to the ASTM standard for triaxial tests and at this rate, the soil exhibited nonlinear elastic behavior. As the loading rate increased, the relationship became bilinear. Loading rate above 200 mm/min had minimum influence on the stress-strain relationship. Hence a loading rate of 200 mm/min was selected for this study.

The two soils were first crushed into individual particles using a hand held mortar and rubber tipped pestle to avoid breaking the individual particles. The soil was then dried in an oven at 105° C for 24 hours and the moisture level was raised to the desired level by adding water. The samples were then sealed in two plastic bags and stored for 24 hours to allow the moisture to reach equilibrium. Cylindrical samples for the triaxial tests were prepared using the method of undercompaction described by Ladd (1978). The cell was filled with water after locating the cell jacket correctly and the confining pressure was applied using compressed air source. A maximum axial stress level selected for unloading was 138 KPa and this selection was based on the dynamic load exerted by a skidder wheel. Confining pressures of 17.2, 24.1, 34.5, and 41.4 kPa (2.5, 3.5, and 6 psi) were chosen to simulate the lateral ground pressure on the soil column.

The specimens were subjected to an axial stress level of 138 kPa and then unloaded to simulate the first pass of a vehicle. Two more cycles of loading and unloading were carried out to simulate a total of three passes. For the SM soil, the specimens were loaded to various axial stress levels and were then unloaded after primary loading was completed. Attempts were made to load the soil to 50 and 75% of the maximum deviatoric stress levels to observe the elastic/plastic behavior upon reloading and unloading. Once the unloading was completed, the specimens were reloaded to the maximum desired level and unloaded twice. The axial stress levels were increased for each loading cycle and then loaded a fourth time to failure. The test results for the sandy-clay at a confining pressure of 41.4 kPa is shown in Figure 1.

MODEL FORMULATION

A typical stress-strain relationship from triaxial test (Figure 1) show that an elastic-plastic model will fit the soil behavior the best. Assuming Mohr-Coulomb failure criteria (Brandon, 1987), the yield function for the plastic behavior is given by:

$F(\sigma) = c + \alpha\, p - q = 0$ [1]

where $p = (\sigma_1 + \sigma_3)/2$, $q = (\sigma_1 - \sigma_3)/2$, c is the vertical intercept on the q-axis, and α is the slope of the failure surface. Using the incremental plasticity procedure, the total strain can be divided into elastic and plastic components:

$d\varepsilon = d\varepsilon^e + d\varepsilon^p = D_e^{-1} d\sigma + \lambda(\partial Q/\partial\sigma)$ [2]

where, $d\varepsilon^e$ = the incremental elastic strain, $d\varepsilon^p$ = the incremental plastic strain, where D_e = elastic constitutive matrix, λ = a proportionality constant and Q = the plastic potential.

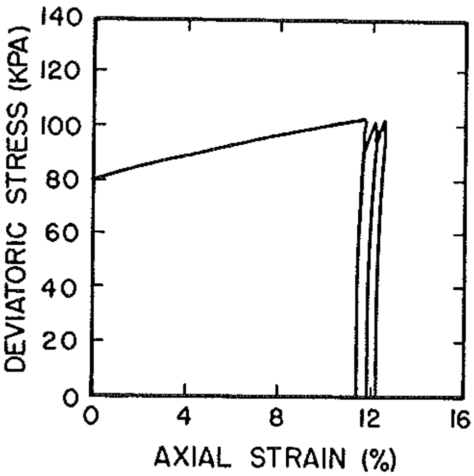

Figure 1. Stress-strain relationship for sandy-clay soil at a confining pressure of 41.4 kPa

Premultiplying by D_e throughout:

$$D_e d\varepsilon = d\sigma + \lambda\, D_e(\partial Q/\partial\sigma) \quad [3]$$

Now using consistency condition stated as:

$$dF = (\partial F/\partial\sigma)\, d\sigma = 0 \quad [4]$$

and substituting $d\sigma$ from equation 3 into 4

$$\frac{\partial F}{\partial \sigma}(D_e d\varepsilon - \lambda D_e(\partial Q/\partial\sigma)) = 0 \quad [5]$$

Solving for λ in equation 5 and substituting back into 2, the following relationship can be obtained for the incremental stress and strains:

$$d\sigma = D_e d\varepsilon - \frac{\left(D_e \frac{\partial Q}{\partial \sigma}\right)\left(\left(\frac{\partial F}{\partial \sigma}\right)^T D_e\right) d\varepsilon}{\bar{A} + \left(\frac{\partial F}{\partial \sigma}\right)^T D_e \frac{\partial Q}{\partial \sigma}} \qquad [6]$$

where, D_e = elastic constitutive matrix, Q = plastic potential and it is equal to F for associated soils. $\bar{A}$ = hardening function = 0 for perfect plastic material. Equation (6) can be written as:

$$d\sigma = (D_e - D_p)\, d\varepsilon = D_{ep} d\varepsilon \qquad [7]$$

where D_{ep} = the elastic-plastic matrix = $D_e - D_p$, and D_p = the plasticity matrix. Using the Mohr-Coulomb yield function F for two dimensional plane problems as,

$$F = c + \alpha\left(\frac{\sigma_x + \sigma_y}{2}\right) - \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \sigma_{xy}^2} \qquad [8]$$

The D_{ep} matrix can be written as

$$D_{ep} = \begin{bmatrix} K + \frac{4}{3}G & K - \frac{2}{3}G & 0 \\ K - \frac{2}{3}G & K + \frac{4}{3}G & 0 \\ 0 & 0 & 2G \end{bmatrix} -$$

$$\frac{1}{B} \begin{bmatrix} (4G^2A^2 - 4GAC + C^2) & (-4G^2A^2 + C^2) & (-4ABG^2 + 2BCG) \\ (-4G^2A^2 + C^2) & (4G^2A^2 + 4ACG + C^2) & (4ABG^2 + 2BCG) \\ (-4ABG^2 + 2BCG) & (4ABG^2 + 2BCG) & (4B^2G^2) \end{bmatrix} \qquad [9]$$

where K = bulk modulus; G = shear modulus
$\bar{B} = 4A^2G + C\alpha + 2GB^2$; $C = \alpha(K + G/3)$

$$A = \frac{\sigma_x - \sigma_y}{4\sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \sigma_{xy}^2}}; \qquad B = \frac{\sigma_{xy}}{\sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \sigma_{xy}^2}}$$

RESULTS AND DISCUSSIONS

In order to determine the parameters in the constitutive model given in Equation [9], maximum deviatoric stress levels (stress at failure) were determined from triaxial test results and were plotted in the p-q space to yield α and c. Modulus of elasticity (E) values were calculated for the two soils by averaging the slopes of the initial portion of the curves for all of the tests. Since volume change data could not be recorded, poisson's ratios for sandy-clay soils and sandy-silt soil were assumed to be 0.45 and 0.35 respectively. The model parameters obtained are summarized in Table 1.

Table 1. Constitutive model parameters for sandy-clay and sandy-silt soils

Soil	E MPa	ν	ϕ (°)	c (kPa)	α
SC	107	0.42	15	31.7	0.23
SM	148	0.35	30	24.8	0.43

Knowing these values, the elastic-plastic constitutive matrix was evaluated for the sandy-clay soil as,

$$D_{ep} = \begin{bmatrix} 280.8 & 203.4 & 0 \\ 203.4 & 280.8 & 0 \\ 0 & 0 & 75.3 \end{bmatrix} - \frac{1}{(154.8A^2 + 38.7B^2 + 12.8)}$$

$$\begin{bmatrix} (77.4A - 55.7)^2 & (-5990.8\,A^2 + 3102.5) & (-5990.8AB + 4309.6B) \\ (-5990.8\,A^2 + 3102.5) & (77.4A + 55.7)^2 & (5990.8AB + 4309.6B) \\ (-5990.8AB + 4309.6B) & (5990.8AB + 4309.6B) & (77.4B)^2 \end{bmatrix} \quad [10]$$

and for the sandy-silt soil as,

$$D_{ep} = \begin{bmatrix} 237.5 & 127.8 & 0 \\ 127.8 & 237.5 & 0 \\ 0 & 0 & 109.6 \end{bmatrix} - \frac{1}{(219.3A^2 + 109.6B^2 + 33.8)}$$

$$\begin{bmatrix} (109.6A - 78.6)^2 & (-12020.9A^2 + 6170.1) & (-12020.9AB + 8612.2B) \\ (12020.9A^2 + 6170.1) & (109.6A + 78.6)^2 & (12020.9AB + 8612.2B) \\ (-12020.9AB + 6170.1B) & (12020.9AB + 8612.2B) & (109.6B)^2 \end{bmatrix} \quad [11]$$

The initial reaction to the triaxial results was to approximate the stress-strain relationship with two straight lines of different slopes. The limitation with such a model would be that it can not be used to simulate the unloading and reloading situations and to predict the residual strains resulting from such loading. An elastic-plastic model, on the other hand, would be capable of predicting any permanent deformation resulting from unloading.

The constitutive model developed in this study was compared with other published elastic-plastic models (Siriwardaine and Desai, 1981, Mizuno and Chen, 1981, and Zienkiewicz, et al., 1969). These models are similar in their derivations. However, they are different based on the yield criterion and flow rules selected for the derivation. Also, the model parameter values obtained in this study could be significantly different because, the rate of loading used in this study is considerably higher than those found in the literature. The assumption of the associated flow rule used in this study could also cause significant influence because soils generally do not exhibit associated flow behavior.

The constitutive models developed for the two soils were evaluated by simulating a triaxial test at a confining pressure of 28 kPa. The simulation was conducted using an incremental loading procedure. The total load of 138 kPa was applied in steps of 2 kPa. The sample was than unloaded to a zero level of deviatoric stress in one step and reloaded and unloaded twice to a level of 138 kPa to simulate three passes of a vehicle. Simulation results is compared against experimental data in Figure 2 for sandy-clay soil. Considerable discrepancy between the two is observed at higher strain levels, however, the unloading and reloading compared well. Possible reasons for the observed discrepancy are: (a) during many tests, the failure point could not be determined accurately, (b) the poisson's ratio values assumed probably are lower then the actual, (c) large variation in the test data between replications at low confining pressures.

In order to determine the effect of poisson's ratio on predicted results, simulation was conducted for different values of ν and the results are illustrated in Figure 3. As the ν value increased the agreement between the predicted and experimental data improved considerably. This may mean that the volume measurements during triaxial tests are critical so that the value of poisson's ratio can be determined accurately.

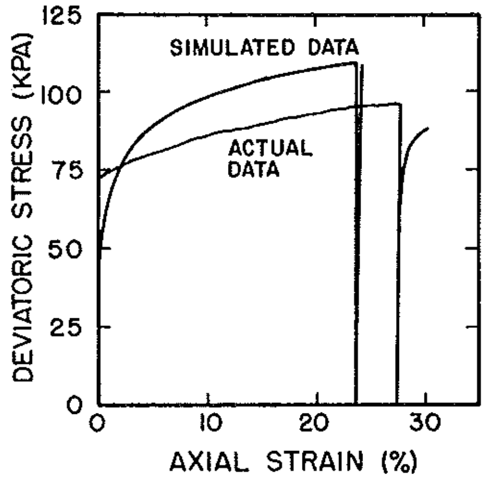

Figure 2. Comparison of predicted and actual stress-strain relationship for sandy-clay soil at a confining pressure of 28 kPa

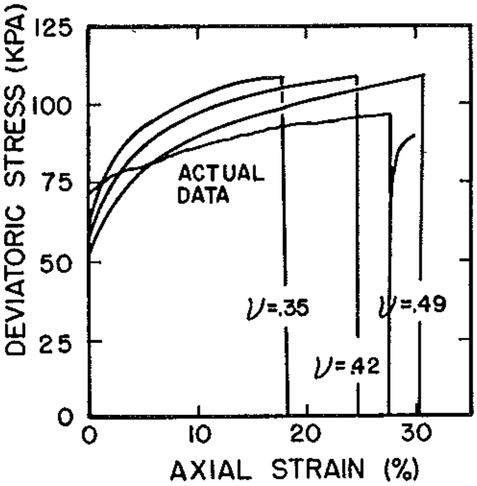

Figure 3. Effect of varying Poisson's ratio on the predicted stress-strain relationship

Siriwardane and Desai (1981) used a similar constitutive model in the FE analysis and therefore, it is reasonable to assume that the constitutive relationships developed should be applicable for FE analysis of soil compaction resulting from multiple passes of tractors. Incremental loading technique may be appropriate for the analysis of such problems.

CONCLUSIONS

The conclusions derived from this study are:

1. The stress-strain relationships obtained from triaxial tests indicate that the soil behavior under dynamic condition can be described by an elastic-plastic model.
2. Elastic-plastic models suited for finite element analysis of the soil-wheel interaction problem have been developed for two agricultural soils.
3. A comparison of experimental and predicted results show an over prediction at higher strain levels.
4. Poisson's ratio value had a significant influence on predicted results. Volume measurements during triaxial tests are necessary for improving the accuracy of the model.

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MODELLING OF CROP SEEDLING EMERGENCE AS A FUNCTION OF SOIL MOISTURE AND DIRECT DRILLING OPENERS

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ABSTRACT

Laboratory and field experiments to determine the effects of soil moisture and opener designs on seedling emergence sown in untilled soil, are described. Results have shown that the choice of appropriate opener(s) was of paramount importance when seeding into limited soil moisture. An inverted-T opener gave higher seedling emergence than the hoe or triple disc openers tested. Prediction models, which related likely seedling emergence to loss of in-groove soil r.h. for selected openers in relatively dry soil, were developed. In a favourable seed microenvironment, seedling emergence counts were negatively correlated (r = -0.89) with soil moisture content and with variations in seeding depth.

INTRODUCTION

Within the broad range of non-limiting seed-soil biological and chemical conditions, the stresses imposed by physical factors such as moisture are the dominant forces limiting seed germination and emergence. The mechanisms of soil moisture availability to seeds sown in cultivated soil has been extensively studied. According to Hillel (1972) soil moisture potential affected seed germination and emergence either directly through its effects on moisture conductivity or through effects on temperature enhancing physiological processes during embryonic development. Hadas and Russo (1974) reported that water uptake from the soil adjacent to the imbibing seeds reduced the matric potential at the seed surface rather than the bulk soil.

Soil moisture near the surface, although difficult to measure accurately (Painter, 1976; Scotter, 1976), controls seed imbibition and germination. Choudhary and Baker (1980) and Rogers and Dubetz (1980) suggested that in drier soils the vapour moisture, the transport of which depended on the degree of soil bulk density, played a major role in determining the extent of seedling establishment.

Adequate soil penetration by seed drill openers has resulted in consolidation and smearing of seed grooves and caused reduced plant populations in untilled dry soil (Choudhary and Baker, 1981b), in soils with adequate moisture (Baker, 1976; Baker and Mai, 1982) and in wetter soils (Chaudhry et al. 1987). These authors and Soane et al. (1975) have emphasized the need to quantify the interactions between drilling machinery and soil parameters in untilled soils. This paper reviews these interactions and the seedling emergence models developed are described.

MATERIALS AND METHODS

Controlled environments experiments: Undisturbed soil blocks in steel bins 1.8 m long, 660 mm wide, and 200 mm deep, were extracted from

"Manawatu fine sandy loam" under permanent pasture, and used as "mini-fields". Existing grass on the soil blocks was desiccated by herbicide. Soil moisture in the blocks was stabilized close to -10 bars before drilling with wheat (Triticum aestivum cv. karamu) using selected test openers. The openers (Choudhary and Baker, 1980) were attached to a moving gantry used for 'drilling' seeds into blocks of soil in the laboratory (Baker, 1976).

A total of six opener treatments were compared. These were: 1. Inverted-T opener followed by harrowing; 2. Hoe opener followed by harrowing; 3. Hoe opener followed by 70 kPa pressure wheel directly over seeds before harrowing; 4. Triple disc opener followed by harrowing; 5. Triple disc opener followed by 70 kPa pressure wheel directly over seeds before harrowing; 6. Triple disc opener covered by loose soil before a 70 kPa pressure wheel application over the top of grooves.

Single rows of 100 seeds were drilled with three replications. Immediately after drilling the blocks were housed in controlled climate rooms pre-set at 20°C, 60% r.h. with daylight of 12 hours at 70 Wm^2, regardless of ambient weather changes. Air samplers used for withdrawing in-groove air for determining r.h. were T-shaped 2 mm i.d. copper tubes, embedded in the grooves immediately following drilling with perpendicular portions protruding out of the grooves. A hygrometer sensor (EG&G model 880 thermo-electric dew point hygrometer), connected to the air sampler, measured the r.h. Daily in-groove r.h. was measured until day 6 and emergence counts until day 18 when emergence had plateaued. Data were analysed to determine relationships between the in-groove r.h. gradients and seedling emergence and survival.

Field experiments: Fortnightly experiments were conducted during Spring-Summer-Autumn irrespective of prevailing weather conditions. Sets of three openers of each type were adjusted on a drill to sow seeds in 150 mm row spacings in a "Ohakea" heavy silt loam under permanent pasture. A total of twelve drillings were accomplished with 4 replications in a randomised block design with effective plot sizes of 4 x 2.6 m^2. Plots were sprayed with herbicide to desiccate vegetation one week before drilling. Soil and climatic conditions varied from extremely dry to wet during the trial period.

Soil moisture at 0-45 mm depth was measured daily in the plots. Seedling emergence counts were taken weekly after drilling until the third week.

RESULTS AND DISCUSSION

Controlled environment experiments: Overall there were low seedling emergence counts as the experiment had started at unusually low initial soil moisture (Table I). The inverted-T and hoe opener treatments gave equal seedling emergence and these were higher than those from the triple disc opener treatments.

TABLE I. Effects of direct drilling openers and covering techniques on seedling emergence and seed fate of wheat, and in-groove r.h. loss rates.

Treatments	Seedling emergence (%)	'Germinated but unemerged' seeds (%) (dead + viable)	Total	In-groove r.h. loss rates (% per day)
1. Inverted-T opener/ harrowed	36.2Bb	(30.4 + 18.2)	48.6Bb	2.34 C
2. Hoe opener/ harrowed	31.1Bb	(30.6 + 0)	30.6Bb	2.77 B
3. Hoe opener + 70 kPa pressure directly over seed/harrowed	37.0Bb	(43.7 + 0)	43.7Bb	1.92 C
4. Triple disc opener/ harrowed	2.5Aa	(68.2 + 0)	68.2Aa	4.23 A
5. Triple disc opener + 70 kPa pressure directly over seed/ harrowed	7.3Aa	(80.8 + 8.0)	88.8Aa	2.32 C
6. Triple disc opener, and loose soil cover followed by 70 kPa pressure over top of grooves	8.4Aa	(68.0 + 23.6)	91.6Aa	2.42 C

Unlike letters in a column show significant differences at $P \leq 0.01$ (capitals) and $P \leq 0.05$ (lower case).

Second order equations for all treatments best explained the daily in-groove r.h. loss and the mean gradients of these were determined (Table I). The inverted-T opener clearly gave the lowest r.h. gradient than both the hoe and triple disc openers where these were followed by harrowing only. However, the gradients of the hoe and triple disc openers improved to levels similar to that of the inverted-T opener when 70 kPa pressure was applied over their covered or uncovered grooves.

Choudhary and Baker (1981b) had shown earlier that liquid soil moisture, although strongly influencing seed germination, had only partially affected seedling establishment. This is illustrated in the performance of the triple disc grooves in which most seeds had germinated but failed to emerge (Table I). The subsurface seedling survival improved as did the r.h. loss gradient when these grooves were covered with loose soil before pressing.

Correlation coefficients for r.h. loss gradient and visible seedling emergence showed a moderate inverse relationship ($r = -0.75$) when subsurface surviving seedlings were also included in emergence data. A simple relationship (Fig. 1) described the expected seedling emergence and subsurface survival, given the selected opener combinations. A relatively low value of the coefficient of determination ($R^2 = 0.59$) suggests that the r.h. measurements explained, albeit partially, the interactions between the openers, seed microenvirnoment and seedling emergence. This was not unexpected as separate experiments have shown that in the presence of desirable seed microenvironments seedling emergence was also highly negatively correlated (r = -0.89) with variations in seeding depth (Choudhary et al. 1985).

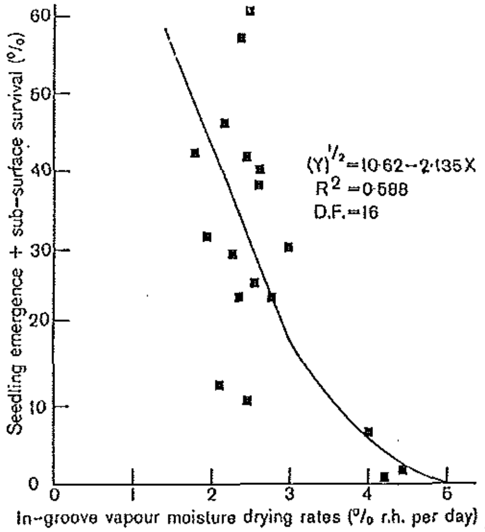

Fig. 1. Effect of in-groove humidity loss rate on wheat seedling emergence and sub-surface seedling survival.

Field experiments: A generally acceptable wheat seedling emergence occurred when the soil moisture was close to field capacity (26%, w/w) (Table II). In the first four seed drillings, there were no differences in seedling emergence of openers. During the fifth to eighth drillings, the soil moisture was below permanent wilting point (16%, w/w) and consequently no seedling emergence occurred.

TABLE II. Effects of direct drilling openers and soil moisture content on seedling emergence (%) of wheat from twelve drilling dates

Drilling No depth	Opener type				Soil moisture content (%, w/w) at 0-45 mm	
	Triple disc	Hoe	Inverted-T	Mean	At drilling	Mean of week 2 after drilling
1	71.6 b	66.6 b	67.3 a	68.4 b	34.6	23.6
2	49.3 cd	55.5 bc	48.7 cd	51.9 cd	18.8	32.2
3	45.0 cd	48.1 c	49.3 cd	47.5 d	29.6	23.5
4	59.1 bc	51.3 bc	64.1 bc	58.2 c	25.5	17.7
5	0 f	0 f	0 f	0 f	12.4	11.5
6	0 f	0 f	0 f	0 f	7.9	5.5
7	0 f	0 f	0 f	0 f	6.0	7.1
8	0 f	0 f	0 f	0 f	5.2	6.6
9	20.5 e	21.1 e	34.6 d	25.4 e	4.2	14.5
10	40.3 d	57.3 bc	54.1 bc	50.5 cd	9.4	15.4
11	58.3 bc	51.8 bc	59.8 bc	56.6 c	11.0	28.1
12	70.5 b	80.9 a	82.6 a	77.2 a	27.8	30.2

Unlike letters in each column show significant differences at $P \leq 0.05$

On the day of ninth drilling, although the soil moisture was below wilting point, some rain followed and recharged the moisture to 22.3%. This promoted some seedling emergence. The inverted-T opener gave higher emergence counts than those from the hoe and triple disc openers.

During the tenth drilling more rain fell and the percentage emergence increased further. However, the emergence differences between the triple disc and inverted-T opener remained in favour of the latter. During the eleventh and twelfth drilling more rain fell recharging soil moisture close to field capacity and the emergence differences between openers disappeared confirming earlier results of Choudhary and Baker (1980).

The correlation coefficient for seedling emergence and the moisture at seed depth in the second week after drilling suggested a moderately high positive relationship ($r = 0.84$). Clearly a linear relationship between wheat seedling emergence and soil moisture in the higher range of availability existed, with the inverted-T giving higher emergence than the hoe or disc type openers. Destructive sampling of the fifth to eighth drillings showed that almost 100% of seeds had germinated. However, seed fate analyses suggested that of the unemerged seedlings, nearly 100% seedlings had survived in the inverted-T opener grooves, whereas only 60% and 42% of subsurface seedlings were alive in the hoe and triple disc grooves respectively.

These results confirmed eariler work that showed that in dry soils the availability of moisture in the vapour form was at least as important for seedling survival as liquid moisture was for seed germination. Furthermore, similar studies conducted in the tropical climate (Choudhary, 1988) have suggested that opener, seed microenvironment and seedling emergence relationships developed in temperate climates were equally applicable in tropical conditions. These experiments were conducted in rice soils where soyabeans, mung beans and corn were sown in the dry season following rice. Seeds sown with the inverted-T seeder gave higher seedling emergence counts both in the previously tilled and untilled soil compared with conventional manual sowing. Again, plant establishment was found to be highly negatively correlated ($r = -0.94$) with seed zone r.h. loss gradient.

In practical situations where an adequate supply of moisture is available any of the three types of openers studied would generally perform equally satisfactorily. Such field conditions usually occur during early spring or late autumn sowing. However, during mid-to-late spring and early-to-mid autumn when soil moisture is on a reducing scale and long dry spells could occur, the choice of an appropriate drill opener would be critical for achieving assured plant establishment. In such circumstances, the disc type openers are least effective in promoting plant establishment while an inverted-T type opener is the most tolerant of adverse conditions.

CONCLUSION

1. These studies highlighted opener designs and seed covering techniques and their interactions with soil moisture and seedling emergence.
2. In soils with adequate moisture, plant establishment appeared to be independent of opener types. Although vapour moisture played a significant role in determining the extent of emergence, it is not

known, however, at what moisture level vapour moisture became the dominant determinant of seedling survival.

3. In relatively dry soils, the geometry of seed grooves largely determined the extent of seedling emergence. In these conditions an inverted-T opener showed a wider range of tolerance of soil and climatic conditions. The triple disc opener was strongly affected by changes in soil and environmental condition and was at greater risk than the inverted-T and hoe openers.
4. The prediction models evolved from these studies explained the interactions between soil moisture, opener types and their effects on crop emergence.

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QUANTIFYING THE INFLUENCE OF CROPPING HISTORY ON SOIL STRUCTURE

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ABSTRACT

Information on rates of change of the structure of different soils under different cropping systems is vital to research in soil conservation. A conceptual model is presented which facilitates quantification of cropping history in relation to rates of change of soil structure. The model relates structural form, structural stability, stabilizing materials, biological factors and forces which may be exerted on the soil. Soil and crop management practices influence the nature and magnitude of forces involved, biological factors, and the level of stabilizing materials. The model is applied, for illustrative purposes, to five different cropping treatments involving the production of corn (conventional tillage) and bromegrass grown for different lengths of time over a 15 yr. period.

INTRODUCTION

Increasing effort is being directed towards the development of strategies which will sustain, or in some instances reclaim, the agricultural productivity of land resources in many parts of the world. Soil structure has a direct impact on a range of processes influencing crop growth. Consequently as new strategies for crop production are being developed, increasing emphasis is being placed on the capability of these strategies to improve soil structure. Soil structure is a dynamic parameter and assessments of the impact of cropping practices on soil structure must be defined in terms of rates of structural change. Such assessments must be appropriate for the farmer's planning horizon, i.e. the extent of change which can be expected within a few years. This paper introduces a conceptual model, or working hypothesis, wherein changes in soil structural characteristics can be related to changes in cropping practice. The form of the model will be illustrated using data collected by Angers et al. (1987) and Baldock and Kay (1987).

THEORY

Soil structure can be defined in terms of both form and stability. Soil structural form is the arrangement of solid and void space in soil. The stability of soil structure, on the other hand, is the ability of a soil to retain its arrangement of solid and void space over time when exposed to different forces.

A generalized function which describes the variation with time, t, of a characteristic, S, of structural form for the cultivated soil condition relative to the value of the corresponding characteristic, S_o, of the reference condition, takes the form

$$\frac{S}{S_o} = f\ (t) \tag{1}$$

Soil in the reference state must be part of an ecosystem which is stable within the time scale of interest.

The first hypothesis upon which the model is based is that the rate of change of a relative value of a characteristic of structural form can be related to two functions which are additive, a biological function and a physical-chemical function. The biological function, B, describes the rate of change in a characteristic of structural form caused by living organisms. The biological function only includes the effect of organisms on structural form; the influence of organisms on the stabilization of structure is considered in the physical-chemical function. The physical-chemical function includes two variables, namely, the force per unit area, F/A, applied to the soil and a stability parameter, $(R)_{SF}$, which is appropriate for the given structural form and force. The two functions would be related to the rate of change in structural form as follows:

$$\frac{\partial\ S}{\partial\ t} = f\ [(R\ )_{SF}, \frac{F}{A}] + f\ [B\ ] \tag{2}$$

The second hypothesis upon which the model is based is that changes in the relative stability characteristics (R/R_o) can be related to changes in the relative level of stabilizing materials, (c/c_o), which are present in the soil, i.e.

$$(\frac{R}{R_o})_{SF} = f\ (\frac{c}{c_o}) \tag{3}$$

The stabilizing materials may be inorganic or organic. Different materials may have different effects on different stability characteristics.

The third hypothesis, upon which the model is based, is that the change in the relative level of stabilizing materials for given soil and environmental conditions and a given crop production system (i.e. crop sequence, tillage, fertilization, weed, insect and disease control, and harvesting practices) can be described as a function of time, i.e.:

$$\frac{c}{c_o} = f(t) \tag{4}$$

Functions of this form could describe the rate of loss of inorganic stabilizing materials through erosion, acidification or salinization, as well as the rate of change in the levels of organic stabilizing materials.

The rate of change in the level of organic stabilizing materials is the difference between the rate of addition, R_A, of plant, animal or industrial materials as well as products of microbial transformation, and the rate of loss, R_L, of stabilizing materials through erosion, translocation within the profile and by transformation and mineralization by organisms, i.e.

$$\frac{dc}{dt} = R_A - R_L \tag{5}$$

RESULTS AND DISCUSSION

There are few data from long-term studies of contrasting cropping systems which can be used to illustrate the form of equations (1) to (5). The most comprehensive data set are those of Low (1955, 1972) and Greacen (1958). Studies of mixtures of cropping systems maintained over short periods do not normally provide data which can be used to estimate the rate of change in soil structure caused by a given cropping systems. However, the model provides a method of relating measurements of soil structure made at a given time to the preceding cropping history. This approach can be illustrated using data reported by Angers et al. (1987) and Baldock and Kay (1987). These authors assessed the impact on soil structural characteristics of two different crops (corn and brome grass) which had been grown for five different time sequences over a 15-yr period (Table 1). Soil from the plots which had been in bromegrass continuously for 15 yr is taken as the reference state. Negligible erosion has occurred on the sites and there have been no major changes in pH, exchangeable Ca or Mg, organic carbon, inorganic carbon and total nitrogen (Baldock and Kay, 1987). Changes in stability are believed, therefore, to be due to changes in the levels of specific organic stabilizing materials. Lacking information on either the identity of organic stabilizing materials which control a given stability characteristic, or the rates of gains or losses of this constituent, relations for equations (4) and (5) have been assumed for the two cropping systems. Firstly, it is assumed that during the production of bromegrass $R_A >> R_L$ whereas when corn is produced using conventional tillage practices $R_A << R_L$. Therefore the rate of change in the level of stabilizing constituent during bromegrass production is positive and is assumed to be described by a function of the form:

$$\frac{c_i}{c_o} = 1 - e^{-k_1 T_i} \tag{6}$$

where c_i is the level of aggregating constituent contributed by bromegrass at the time, T_i (yr), of period i in which the bromegrass is grown and k_1 is a rate constant. The value of k_1 would be expected to be influenced by soil characteristics, plant species and plant growth characteristics. It may also differ for different stabilizing materials. The rate of change in level of stabilizing materials when corn follows bromegrass is negative and is assumed to be described by a function of the form:

$$\frac{c}{c_i} = e^{-k_2 t_i} \tag{7}$$

where t_i indicates the length of time (yr) between breaking of the sod grown in period (i) and the time (yr) under consideration (t). Values of k_2 would be expected to be influenced by soil characteristics, tillage and other soil management factors as well as plant species.

The relative level of stabilizing materials, c/c_o, after n sequences of bromegrass-corn is represented by the sum of contributions from each period, i.e.

$$\frac{c}{c_o} = \Sigma_{i=o}^{n} \, (1-e^{-k_1 T_i}) e^{-k_2 t_i} \tag{8}$$

Equation (8) represents a specific form that the function given in eqn (4) might take.

The form of the model can be illustrated by assigning values to the coefficients k_1 and k_2 and then calculating c/c_o after the 15th year for the five different cropping histories. The following relation was arbitrarily set:

$$k_1 = k_2 = 0.4 \text{ yr}^{-1} \qquad (9)$$

The value of k_2 is similar in magnitude to values for resistant plant material and soil biomass calculated by Jenkinson and Rayner (1977). The plots had been in forages for an extended period prior to the past 15 years, and therefore at the zeroth period and T = t = 0, $c/c_o = 1$. Values of c/c_o for the five cropping histories were calculated using equations (8) and (9) and are given in Table 1.

Values of c/c_o can then be used to construct functions of the form of eqn. (3). The tensile strength of individual soil aggregates (2.0 - 4.7 mm in diameter) and the compression index of beds of aggregates from four of the cropping treatments were measured by Angers et al. (1987). The percentage of water stable aggregates greater than 1 mm in diameter was measured Baldock and Kay (1987) on the five treatments. The relative stability characteristics can be calculated, using the values for the continuous bromegrass (B_{15}) as the reference, and then plotted against the relative level of stabilizing materials (Fig. 1). The most significant feature of this figure is that the relation between c/c_o and the stability parameters is different for different stability characteristics.

CONCLUSIONS

The model provides a unifying framework for combining theories which describe biological, physical and chemical processes relevent to soil structure.

The following types of applications of the model are conceived:
- a quantitative framework for assessing the extent and nature of impact of new soil and crop management practices on the rates of change of soil structure
- use of relative values of structural form, structural stability, level of aggregating constituents and biological activity to assess the "quality" of a soil at any point in time
- a framework for characterizing the susceptibility of soil to structural changes due to cropping systems.

Assessment, refinement, validation and application of the preceding model will require extensive research carried out on soils of different type and degree of degradation, and under different climatic conditions, crops and soil management practices.

Table 1. Cropping sequences and relative level of stabilizing materials at the end of 15 yr calculated using equations (8) and (9)

Cropping Sequence	$(c/c_o)_{15}$
Continuous Corn[1] (15 yr)	0.00
Bromegrass (9 yr) - Corn[1] (6 yr)	0.09
Corn[1] (13 yr) - Bromegrass (2 yr)	0.55
Bromegrass (12 yr) - Corn[1] (2 yr) - Brome/alfalfa (1 yr)	0.63
Continuous Bromegrass (15 yr)	1.00

[1] Conventional tillage practices employed, i.e. fall plowing, spring secondary tillage

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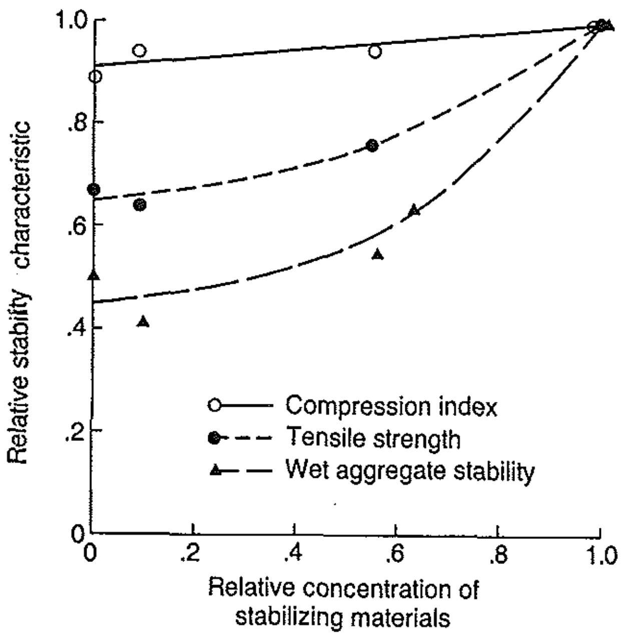

Figure 1. Increase in relative compression index and tensile strength (Angers et al. 1987) and wet aggregate stability (Baldock and Kay 1987) with calculated relative level of stabilizing material.

MODELING OF THE SOIL/ROOTS WATER MOVEMENTS IN THE TWO DIMENSIONAL CASE FOR ANY SPATIAL POSITION OF ROOTS

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ABSTRACT

This paper presents a theoretical approach to analyse the effects of the soil hydrodynamic properties, climatic conditions and spatial position of roots on plant water stress. Theoretical calculations in order to predict 'soil/roots' water flows are made in the two-dimensional case, assuming that the Darcy law applies to predict water movements in the unsaturated zone. The results are based on several simulations and provide a comprehensive approach of the 'climate/soil hydrodynamic properties/spatial position of roots' relationships.

INTRODUCTION

The use of water in agricultural conditions may be the most limiting factor for the growth of plants, particularily for high potential evaporation areas. It has been demonstrated in field conditions that the spatial root system characteristics are very important to insure a satisfactory water use. More precisely, field experimental observations showed that different positions of the roots into the soil (regularly distibuted or not) may induce differences in the water use and subsequently, the plant water stress (Tardieu et Manichon, 1986; Tardieu et Manichon, 1987; Tardieu, 1987). Thus, the spatial position of roots has to be taken into account in the 'soil/climate/roots' relationships analysis.

According to a theoretical point of view, most of the models available in the literature take into account one single root in order to study the soil/root water transfers (Passioura and Cowan, 1968). Some prior works take into account several roots (Baldwin et al., 1972; Neuman et al., 1975; Molz, 1981) but the proposed approachs don't produce a general physically based model to study in various 'climatic/soil/roots' conditions the plant water stress.

This paper proposes a general physically based model to analyse the 'climate/soil/roots' relationships using numerical calculations. It takes into account in the 2 dimensional case the potential climatic conditions, the soil hydrodynamic properties and the spatial position of roots.

THEORY

Main hypotheses

The main hypotheses are the following: (i) the soil is regarded as homogeneous, (ii) the initial soil water potential is assumed as uniform, (iii) the root water potential is the same for all roots at a given time, (iv) the variations of the root water potential versus time are comprised between given upper (0 m) and lower boundaries (- 150 m).

The main input file of the proposed modeling are (i) the basic hydrodynamic soil properties, (ii) the position of the roots on the plane, and (iii) the potential evaporation.

Finite element grid layout.

An original procedure is given to compute automatically the finite elements grid layout according to the given position of the roots. This numerical scheme provides automatically an optimal finite element layout for any 2 dimensional spatial position of roots.

Root water potential estimation

The root water potential is estimated at each time step using an iterative procedure which calculates the 'best' root water potential estimate *in order to minimize the* plant water stress, assuming that the root water potential varies between a minimum value (-150 or -200m) and a maximum value (0.).

RESULTS

Results for various soils, climatic conditions and root position are presented.

First, assuming a non-regular spatial distribution of roots (Fig. 1), an example of map of the soil water potential after several days of simulation is given that show it exists a strong relationship between the root position and water uptakes (Fig. 2). Furthermore, according to data that are not presented here, the effects of water movements from the soil to the root zone during the night (when no evaporation occurs) appear clearly.

Second, the variations of the root water potential and the activity of roots during night and day are presented during 7 days of water movements simulation and the results agree with the common knowledge about the relationships between soil moisture and root uptakes (Fig. 3).

Finally, simulations are presented in order to combine the effects of the initial water content, soil hydrodynamic properties, spatial root position anf climate on the plant water stress (Tab. 1). It is showed that (i) when the soil is very and continuously wet, no stress appears, (ii) when the soil is drier, the effects of limiting soil properties, spatial root positions and potential evaporation appear clearly on the plant water stress.

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Ks (*)	PET = 3 MM/D 10^{-4}	10^{-5}	10^{-6}	PET = 6 MM/D 10^{-4}	10^{-5}	10^{-6}
(1)	1.000	1.000	1.000	1.000	1.000	1.000
(2)	1.000	1.000	1.000	1.000	1.000	0.985
(3)	1.000	1.000	1.000	1.000	1.000	0.945

(a)

Ks(*)	PET = 3 MM/D 10^{-4}	10^{-5}	10^{-6}	PET = 6 MM/D 10^{-4}	10^{-5}	10^{-6}
(1)	0.672	0.672	0.594	0.343	0.343	0.315
(2)	0.672	0.668	0.539	0.343	0.342	0.284
(3)	0.672	0.642	0.433	0.342	0.335	0.227

(b)

Table 1: 'Actual evaporation/potential evaporation' ratio as influenced by the soil hydrodynamic properties, root positions, and climate.
(1) 50 regularly distributed roots; (2) 50 non-regularly distributed roots; (3) 20 non-regularly distributed roots.
(a) initial water potential = -5m.
(b) initial water potential = -50 m.
(*) saturated hydraulic conductivity (m/s).

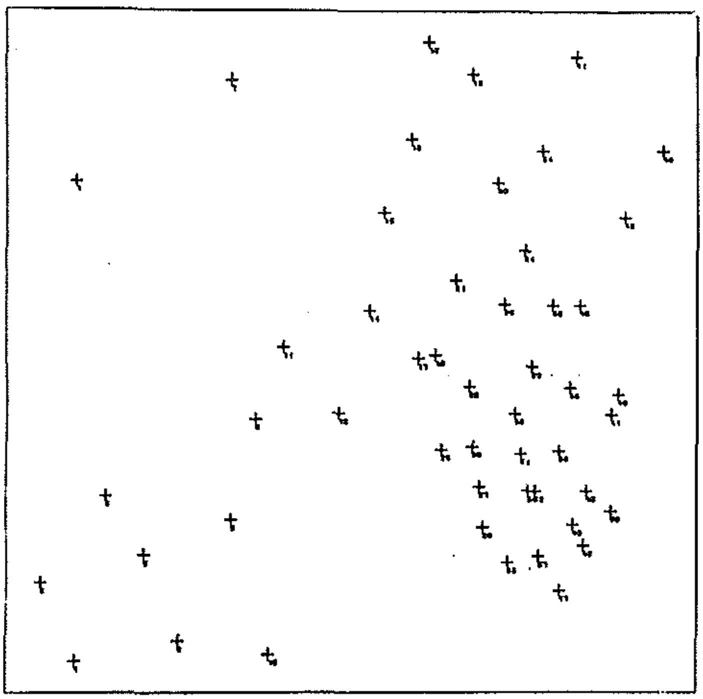


Figure 1: Example of non- regular spatial distribution of roots (50 roots).

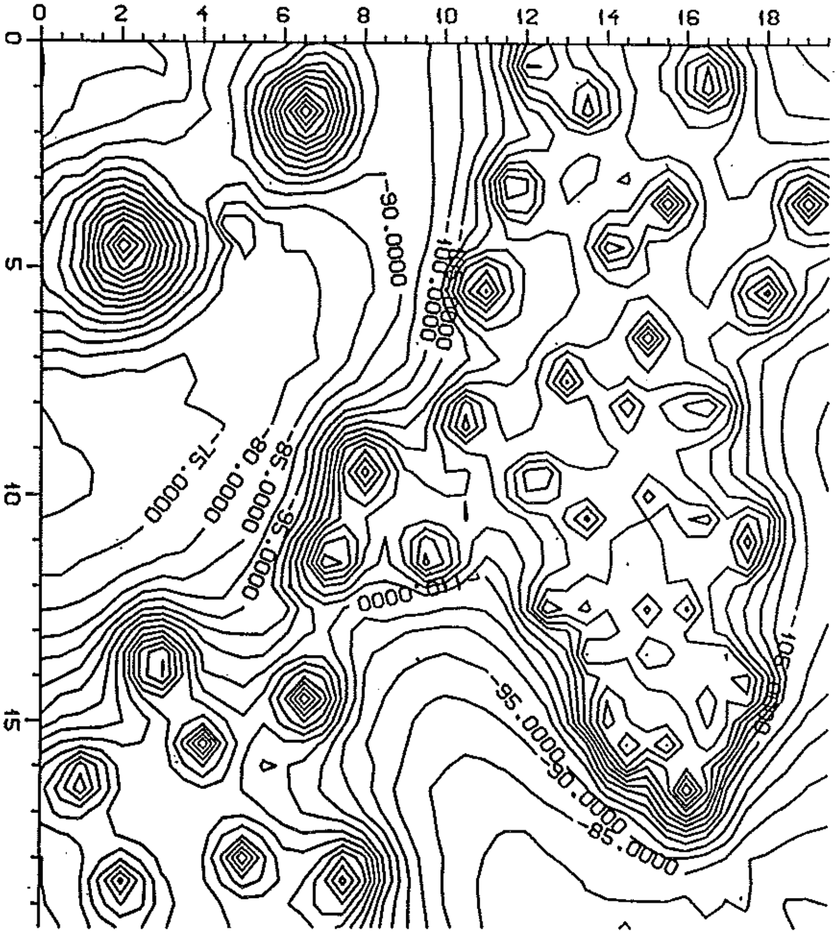
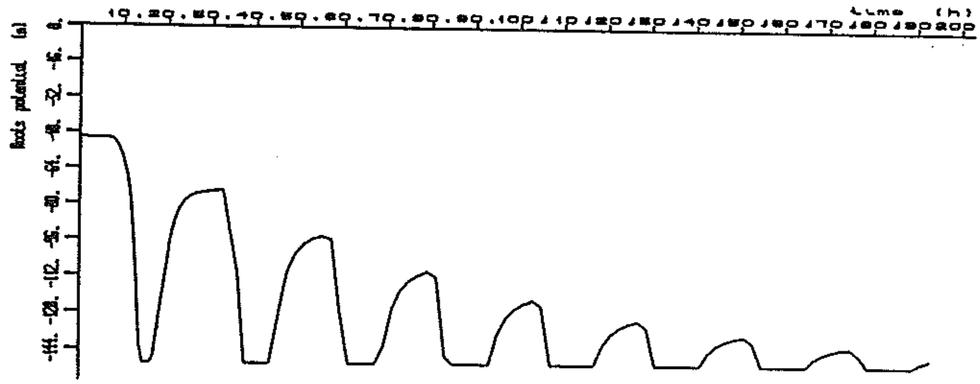


Figure 2: Soil water potential distribution after 3 days of evaporation (50 non-regularly distributed roots, initial soil water potential = -50m, low unsaturated hydraulic conductivity).

(a)



(b)

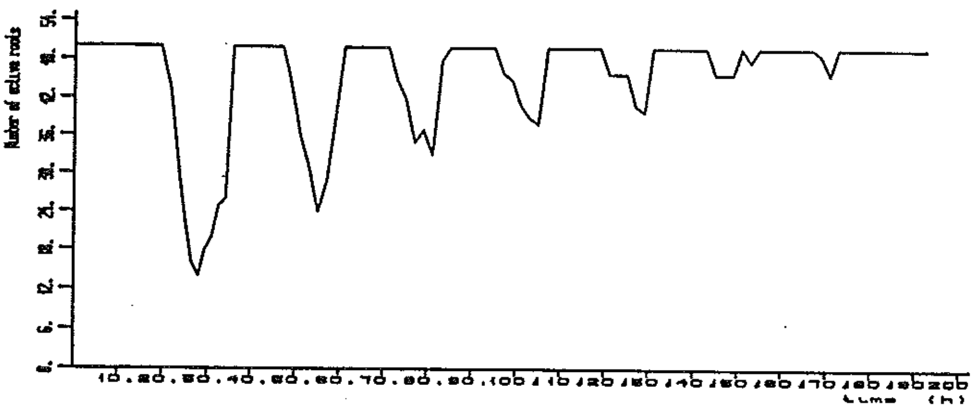


Figure 3: (a) Roots water potential versus time
(b) Number of active roots versus time
(50 regularly distributed roots, initial water potential = -50 m, low unsaturated hydraulic conductivity).

A MODEL OF THE EFFECTS OF TILLAGE-INDUCED SOIL SURFACE ROUGHNESS ON EROSION

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ABSTRACT

Tillage-induced soil roughness has important consequences to erosion. The relief and the shape of the surface will affect raindrop detachment of soil particles, entrapment of particles in depressions, and overland flow of water. Models of these effects were developed based upon a physical description of the soil surface, which include raindrop detachment on inclined surfaces, and the volume and aerial extent of ponded storage. The model of erosion is expressed as a function of an index of roughness to facilitate the use of roughness as a prediction tool. The reduction of the normal component of raindrop impact is the major contributor to the reduction of soil erosion and decreases erosion about 50 percent on typical primary tilled surfaces.

INTRODUCTION

One consequence of tillage-induced roughness that affects erosion is depressions that collect water and sediment during rainfall. Sediment deposition is directly related to the amount of water that can be collected which depends upon rainfall and infiltration as well as the shape of the soil surface. Onstad (1984), used microrelief data and a modified Moore and Larson (1979) model to calculate storage. The upper limit of depression storage being achieved when 100 percent of the area was contributing to runoff. His calculated storage values ranged up to about 1.0 cm of water. These depressions not only provide temporary water storage but also act as receptor sites for the deposition of detached soil particles (Falayi and Bouma, 1975). Moreover, a large depression storage occurs on surfaces where the impact angle and the area impacted by each raindrop may also reduce soil detachment (Moldenhauer and Kemper, 1969; Moldenhauer, 1970; and Linden, 1979). Our purpose is to present a model of the processes contributing to erosion from a soil surface roughened by tillage.

METHODS AND PROCEDURES

A method similar to Moore and Larson (1979) and Onstad (1984) but, with special attention to the boundary or edge conditions of limited size samples, was used to compute the space which could be occupied by sediment, water, and ponded surface areas. Our approach assumed that a microrelief data set represented the entire universe so that depressions which formed continuous channels connected to the edge of the universe were contributing to runoff instead of depression storage. In order to avoid very large boundary effects, depression storage was calculated only in the area of a central window of the microrelief data set which was approximately one-half the area of the entire data set. The window was less likely to have depressions connected to the edge than the surrounding border area because of its separation from the edge.

A procedure of finite-height increments was used for classifying depressions, computing areas, and accumulating space volumes on microrelief data sets. Ponded-surface elevations Z were incremented upward from the minimum elevation by 1/100 of the range of elevations. At each Z, the ponded area in isolated depressions was determined and the appropriate depression storage (area x depth increment/window area) was calculated. Storage for each increment was added to the previous accumulated storage S(Z), until no isolated depressions remained in the window subsample. The fractional area in isolated depressions A(Z), depression storage S(Z), and runoff R(Z) during the storage process as functions of Z were fit to appropriate models with standard regression techniques.

Microrelief data sets were selected that met the following criteria: small grid size so that the assumed square-wave-floor model is justified; and a large number of cells in both directions to minimize the boundary effects. The 159 data sets (Linden and Van Doren, 1986) represented a wide range of surface roughness conditions.

RESULTS AND DISCUSSION

Regression analyses showed that the best roughness index to use as a predictor of the maximum depression storage S_{max} was a combination of the LD and LS roughness parameters defined as:

$$Q = (LD \times LS)^{1/2} \qquad [1]$$

where LD is the limiting relief difference and LS is the limiting slope defined by Linden and Van Doren (1986). LD and LS are computed by statistical techniques from microrelief data sets. The best-fit expression for the upper limit of depression storage is:

$$S_{max} = .382\ Q - .017\ Q\ L - .077;\ r^2 = 0.79,\ n = 159 \qquad [2]$$

where S_{max} is the upper limit to depression storage [cm], Q in $cm^{1/2}$ is the roughness index defined by Eqn. 1, and L is the land slope [%]. Q varied between 0.5 and 2.5 $cm^{1/2}$ while L varied between 0.2 and 10.0% on the 159 data sets. Depression storage varied between 0.1 and 1.0 cm with the maximum depression storage occurring on surfaces that had fresh primary tillage. These values are similar to those reported earlier (Onstad, 1984; Moore and Larson, 1979; and Linden, 1979).

Storage S(Z), runoff R(Z), and fractional depression ponded area A(Z) as functions of height Z are shown in Fig. 1 for three data sets. The three data sets shown in Fig. 1 typify low, medium, and high depression storage surfaces. The maximum A(Z) is nearly equal for each of the data sets and occurs approximately at the height where the rate of change of storage S(Z) is greatest (Fig. 1). A(Z) decreases after reaching a maximum because what was depressional ponded area now becomes a runoff channel. It should be noted that the total ponded area, which includes runoff routes, would not decrease, since the total ponded area approaches the limit of 1.0. Runoff R(Z) during depression filling is significant and increases rapidly as depression storage approaches its maximum value. It appears that runoff during depression filling is equal to or greater than the amount of water being retained in isolated depressions (Onstad, 1984).

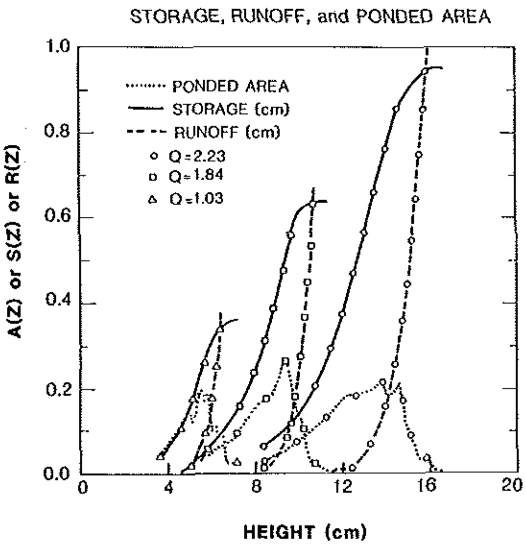

Figure 1. Storage S(Z), runoff R(Z) and fractional ponded area A(Z) plotted as a function of height Z for 3 representative data sets.

It was observed that S(Z), A(Z) and R(Z) could each be normalized because of the consistent shape of the curves (Fig. 1). Curves of S(Z), for example, were normalized by expressing storage on a relative scale, $[S(Z)/S_{max}]$, and Z as a transformed variable defined by:

$$Z' = 1/LD(Z - Z_{0.5}) \qquad [3]$$

where Z is the elevation above the minimum, LD is the limiting difference roughness parameter, and $Z_{0.5}$ is the elevation at which the depression storage was 50% of its maximum value. The ability to normalize the relationships clearly indicates that intermediate ponding and storage as well as the maximum depression storage can be characterized for surfaces having different LD and Q values, since the relationships have similar shapes for different surfaces.

The A(Z) data (Fig. 1) clearly shows that small volumes of ponding, which are less than the maximum depression storage, cover less area on rough surfaces (high Q) than on smooth surfaces (low Q). The smaller areas covered by isolated ponds during the initial phases of storage on rough surfaces implies that less surface is available to receive deposition of sediment. However, the limit to this sediment entrapment is reached sooner on smooth surfaces because of the limited volume of the depressions.

Soil surface area and the inclination of surfaces that receive the impact of raindrops both may affect soil detachment in addition to differences in deposition of sediment noted above. Increased soil surface area reduces the impact force because raindrops are spread over a larger area so that the force per unit surface area is less, when compared to raindrops striking an equivalent horizontal surface (Fig.2). Moldenhauer (1970) speculated that this may be part of the reason for increased resistance to sealing on rougher surfaces. Inclination angle of surface segments may also influence the forces exerted at the point of raindrop impact because of the "glancing blow" effect. Raindrop impact forces may be partitioned into components which are normal and tangential to the soil surface as illustrated in Fig. 2. As the inclination angle increases the normal component of the force is reduced. Soil detachment by raindrops occurs as the normal component of the impact is transferred to a complex pattern of water and particle movement away from the point of impact.

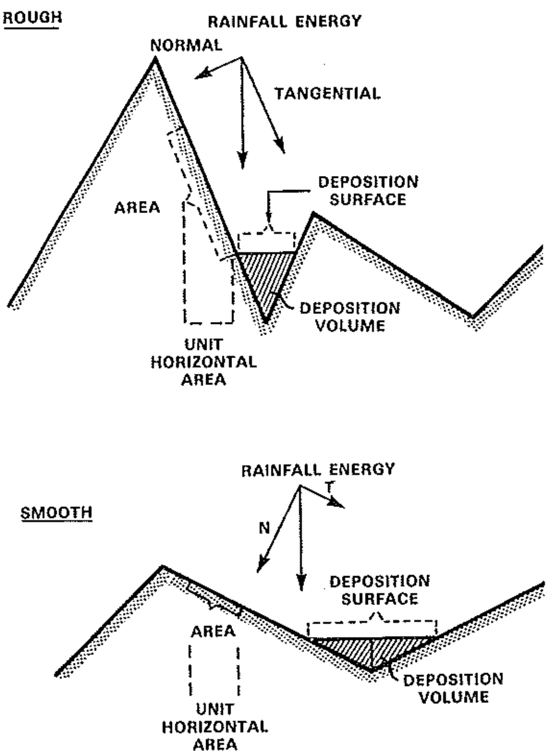

Figure 2. A simplified schematic of two contrasting surfaces (rough and smooth) showing the difference of soil surface area, normal and tangential raindrop energy, and the depositional surface area which affect erosion.

The normal component of raindrop impact can be computed as:

$$P_N = (\cos r/SA)P \qquad [4]$$

where cos r is the cosine of the mean angle of inclination, SA is the soil surface area per unit horizontal area, P_N is the normal component of the precipitation energy, and P is the total precipitation energy per unit horizontal area. The term (cos r/SA) can be thought of as a detachment factor which converts the total rainfall into the effective normal rainfall. This detachment factor (cos r/SA) is a characteristic of tillage-induced roughness that decreases from a value of 1.0 as roughness increases. Although r and SA are both directly measurable parameters of a surface through computation of the LS roughness parameter, (Linden and Van Doren, 1986) they can be obtained indirectly from the roughness index Q. A simple triangular-element-model of surface configuration (Fig. 2) indicates that cos r = 1/SA and regression analyses produced the relationship:

$$\cos r/SA = 1/(.17Q + .97)^2;\ r^2 = .72 \quad n = 130 \qquad [5]$$

Eqn. 5 indicates that a surface with a Q of 2.2, which is a typical value for primary tillage, would reduce the normal impact energy to about 54% of that received on an equivalent horizontal surface. This simple model supports the observations that surface sealing (Moldenhauer, 1970; Falayi and Bouma, 1975) and soil detachment by raindrops (Wang, 1988) was reduced on rough surfaces.

A summary of these combined relationships (detachment and depression entrapment) is shown in Fig. 3 with these simplifying assumptions: 1) soil detachment is a function only of roughness and does not decrease as a function of accumulated rainfall amount, 2) soil detachment does not occur until rainfall exceeds infiltration so that some free water is beginning to accumulate on the surface, 3) roughness decreases with increasing rainfall amounts (Zobeck and Onstad, 1987) and, 4) roughness decreases in proportion to the amount of soil detachment. This model of roughness effects on erosion (Fig. 3) agrees with measured soil splash (Wang, 1988), which shows a 24% reduction in soil splash as the roughness index Q is increased by 1.0.

CONCLUSIONS

The difference in depositional entrapment (ponds) between rough and smooth surfaces has a small affect when compared to the reduced normal energy for detachment from raindrops (Fig. 3). Entrapment (storage) volumes are quite limited while the reduced impact energy continues to affect detachment as long as the roughness persists. An approximate guide indicates that an increase in the roughness index Q of 1.0 unit reduces erosion by about 25 percent. This simple model is in excellent agreement with limited data from the literature.

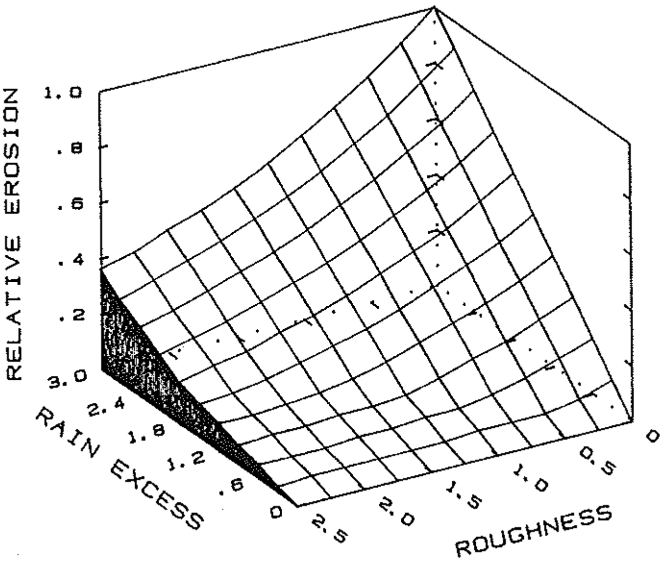

Figure 3. Relative erosion as a function of rainfall excess and the roughness index Q.

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THEORETICAL BASES AND METHODOLOGICAL CONCEPTION ON DETERMINATION OF THE LEVEL OF MACHINE DEGRADATION OF SOILS

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ABSTRACT

Under the term machine degradation of soils (MDS) is meant sharp worsening of soil conditions and soil productivity as a result of negative consequence of irrational wheels and tracks (WT) and digging booms (DB) of mobile technical means (MTM). In consequence of this the soil conditions can worsen not only as a result of compaction but also thanks to the lowering of natural soil productivity. We present here diagnostics of MDS which is based on biological test-method (gutta-diagnostical indication). By the theory of information is determined the level of MDS and prognosticate the decrease of the crop.

INTRODUCTION

In order to determine the reasons and the extent of soil degradation by machines on the example of Estonia, investigations were carried out during many years.

The top-soil in Estonia is extremely mosaic. Within the limits of a small field (ca 5 ha) several different types and kinds of soils can be found. By typology the Estonian topsoil is generally divided into 6 soil regions (A. Lillema, 1958), the two main of which are: sod-calcareous soils (46.7 % of the cultivated area in 1.134 mill. ha); sod-podzolic soils (33.1 %).

Estonian soils of agricultural use can mostly be classified as light and medium with specific resistance 0.030... 0.055 mPa (in the USSR it is determined with special standard strain-gange plough frame). A characteristic feature of the Estonian soils is stones - within the limits of 500...2,000 stones of 10 cm diameter on the field surface. These circumstances should be certainly taken into account when estimating the soil degradation by machines.

METHODS

While carrying out complex investigations on determining machine degradation of soils, 4 main aspects were taken into account:

1) investigations were carried out on earlier uncompacted soils, i.e. on several years' old hayfields;

2) mobile technical means were completed according to the schemes, more frequently used in practice, in the conditions of the Estonian farms;

3) the experiments were carried out on the most characteristic types of soils in Estonia;

4) the system MSC (machine-soil-crop) was studied in the model as well as natural forms.

Studying the problem of compaction in a model form, two points on views were of interest:

1) the experiments were carried out in special mini-vessels, without cultivating the plants up to the crop but until the gutta-forming germs emerged in unnatural conditions (first stage);

2) the experiments were carried out in vegetal vessels cultivating the plants in natural conditions up to complete ripening (second stage).

At one as well as the other experiments (stages) the same unified compressor strain gange equipment was used with the help of which compactions were given at the corresponding repetitiveness of compaction, necessary tensions which were similar to those under caterpillar tracks of the overballasted tractor T-74 with the caterpillar track load of 34 kN.

THEORY

Taking into account the apriory notion of the result of mechanical influence of the mobile technical means (MTM) on soil depending on the character of this influence, code combinations are used. Any subsequency of mechanical influence on the soil can be expressed as fellows:

DB IrS + WI IaS + DB IrS + WT SaS + DB IrS + WT IaS + + DB SaS + ... etc. The code combinations describe the influence of the wheels and tracks (WT) as well as digging booms (DB) depending on the supposed re sult, either impairing soil (IaS), sparing soil (SaS) or improving soil (IrS).

Naturally, the complex estimation of different combinations of the character of mechanical influence on the soil is not a simple task, the more so while in addition to the abovementioned changes of soil condition one is to take into account also the changes of soil productivity. The task was solved by introducing into the estimation model the undetermined index which is calculated by formula:

$$H(Q) = E_Q \log_2 {}^1/E_Q + (1 - E_Q)\log_2 \frac{1}{1 - E_Q} \qquad (1)$$

where $E_Q = \frac{K_o - K_1}{K_o - K_x}$; here $K_o = I$; K_1 and K_x - correspondingly the current and werse indices of yielding capacity in relative units estimated at the common influence of factors changing soil air supply (general porousness) and its productivity (the degree of mixing the humus layer with subsoil

$-B_\xi$. Soil air supply is estimated by relative units for what index A is used - degree of compactness. It is determined with the help of theoretical and experimental investigations in model as well as natural conditions that between index E_Q and above_mentioned diagnostical parameters of soil condition there exists the fellowing dependence:

$$E_Q = \frac{1}{1 - K_x} \left(\frac{1 - Ka}{1 + B_\xi/A} + \frac{1 - Kz}{1 + A/B_\xi} \right) \qquad (2)$$

where K_a and K_z are respectively relative productivities gained as a result of influence estimation of factors of air supply and relative change in productivity. Relative soil air supply is estimated by the index of the degree of compaction

$$A = \frac{\mathcal{E}_a - \mathcal{E}_i}{\mathcal{E}_a - \mathcal{E}_{min}} \qquad (3)$$

where $\mathcal{E}_a$, $\mathcal{E}_i$ and $\mathcal{E}_{min}$ - accordingly coefficients of soil porousness, characterizing its air supply to compaction, after compaction and under the conditions of maximum possible worsened (compacted) condition.

It may happen that in the course of tillage the natural soil productivity can decrease considerably. This decrease is estimated by index B_ξ which characterizes the decrease of productivity concerning diversity of indexes, corresponding to the best and worst state of soil according to its productivity. This index is equal to

$$B_\xi = \frac{H_r - H_{ai}}{H_r - H_d} \qquad (4)$$

where H_r, H_{ai} and H_d - are accordingly the content of humus before the influence, after the influence and worse soil conditions in per cent.

Further, the allowable limit of soils' machine degradation or their agrotechnical bearing capability (A.B.C.) is calculated from the formula (theoretical conception by Prof. V. Katsygin is used)

$$q_s = \frac{K}{(\mathcal{E}_a + 1)(\mathcal{E}_a - \mathcal{E}_s) - \beta e^{-\beta x}} \qquad (5)$$

where K - coefficient of soil volume trample, kN/m^3 (determined with the help od penetrometer), β - coefficient of the distribution of strains in the depth of soil massif, m^{-1} (determined by strain gange put into undisturbed soil massifs at different depths), x - the distance from the supporting surface of the deformer (wheel) to the soil layer under study, in relation to which the index K was determined, m.

RESULTS

As a result of theoretical and experimental investigations the following limit values of agrotechnical bearing capability for soils of Estonia have been determined (Table I). Overcoming these limits leads to machine degradation of soils resulting from their overcompaction.

Table I

Limits of agrotechnical bearing capability of Estonian soils of different mechanical composition at humidity 80 % from FC[xx)]
(co-author R. Lehtveer)

Soil type	Agrotechnical bearing capability, kPa	The area under cultivation, %
Sands[x)]	190...220	15.2
Sandy loams	130...170	31.5
Light clay loams	110...140	26.4
Average clay loams	90...120	12.7
Heavy clay loams	70...90	3.3
Light clays	60...70	1.8
Average and heavy clays	45...50	0.5
Turf-marshy soils	40	8.6

x) The bearing capability of fine-grained sands according to preliminary data relates approximately to the bearing capability of clay loams. More exact data will be acquired by further investigations.

xx) FC - field capacity ("the percentage of water remaining in a wetted soil after the donward movement of water") (R. Heinonen, 1985).

In Table I the upper limit of agrotechnical bearing capability; overcoming this limit of A.B.C. or reducing the porosity coefficient limit shows that machine degradation of soil is taking place.

In case of light and average soils which are more spread in Estonia, under the conditions of field capacity, beyond the border SaS influence, such a condition of the soil is taken where A = 0.34, general porosity $_{\varrho}$ = 47 % and aeration porosity 15 %. Field capacity corresponds to the value of soil moisture 18 %.

The limit of the influence of SaS is considered the result where index B does not exceed 0.13 rel. ind. At the inferior condition we accepted H_d equal to 1.3 %. Relative yields have been acquired as a result of the using the gutta--diagnostical indication method. The author of this method is E. Reppo.

The results of analytical investigations have shown (Table II) that with the help of the given theoretical approach it is possible to get visual imagination of all combinations of the character of mechanical influence of MTM on soil. And what is more, one can estimate also the level on negative influence and single out the influence of compaction factor in the presence of soil productivity factor reducing and vice versa.

As it can be seen from the given Table II, the negative influence of productivity factor is more weighty than compaction factor. It means that stricter demands should be presented to tillage means that to wheels and tracks of mobile technical means.

As in case of the given estimation model we proceeded from the hypothesis of maximum entropy and thermodynamical analogy is assigned to this model, then the smaller values of entropy appear to be the logical consequence when soil is in improved condition and big values at impaired condition. To the limit of sparing soil influence corresponds entropy value equal to 0.23 bit. If we take 0.10 bit as standard then the information value is equal to 1. The last is the basis for further analysis to establish the degree of impairing the physical condition of soil.

DISCUSSION

Analytical investigations have shown that with the help of the given theoretical approach also the reverse task can be solved. Taking into account the corresponding limit of impairing soil condition, the loss of the yield can be prognosticated. In extreme situations of the change of character of mechanical influence of MTM on soil the entropic of the system "machine-soil-crop" can change (on the example of Estonia) while soving cereal crops on average and light sod podzolic soils within the limite of 0.08 to 0.71 bit which in code expression corresponds to the following scheme:

$$WT\ S_aS + DB\ I_rS \text{ and } WT\ I_aS + DB\ I_aS.$$

The method of vegetal miniatures or guttation method of plant germs has proved incomparably more economical and operative. During the first week the total information can already be acquired.

The change of the intensity of guttation in the function from the compactness of soil formation has the shape of parabola with the protuberance up, the top of which is in the spot of maximum intensity of guttation.

CONCLUSIONS

As a final conclusion it should be underlined that with the help of the criterion of uncertainty it is possible to estimate any mechanical influence by machine on soil, investigate the processes of after-effect and prognosticate the level and character of negative results from this influence.

The method for determining the allowable limit of soil sparing (overcoming leads to machine degradation of soils) makes it possible to easily, accessibly and operatively solve the today's problem - the defence of soils from machine degradation, the possibility of estimating the existing and perspective wheels and tracks, balancing the policy of soil sparing and machine-building.

Table II

Complex Estimation of System Condition at Different Combinations of Character of MTM Mechanical Influence on Soil
(Estimation Performed Using Method of Gutta-Diagnostical Indication)

No.	Combination of MTM	Estimation index, characterizing soil condition in relation to: compaction			productivity decrease			Index of combined influence E_Q	Entropy of the system, bit $H_{(Q)}$	Residual uncertainty, bit $I_{(Q)}$	Information value **) z_i	Quantity of relative influences N_y ***)	Gradation of worsened condition of relative standard ****) r_{mb}
		γ *)	A	K_o	H_{ai} *)	B	K_z						
1.	SaS WT + IrS DB	1.20	0.02	0.99	4.0	0.01	0.99	1.25	$10^{-2}_{0.10}$	0.90	1.00	1.00	1.2 SaS
2.	SaS WT + SaS DB	1.25	0.29	0.98	3.6	0.13	0.95	3.66	$10^{-2}_{0.23}$	0.77	0.86	1.20	1.0 SaS
3.	SaS WT + IaS DB	1.30	0.37	0.95	2.0	0.74	0.50	4.38	$10^{-1}_{0.98}$	0.11	0.13	79.8	66.5 IaS
4.	IaS WT + IrS DB	1.40	0.51	0.78	4.0	0.01	0.99	2.70	$10^{-1}_{0.84}$	0.16	0.18	5.7	4.8 IaS
5.	IaS WT + SaS DB	1.50	0.64	0.65	3.6	0.13	0.95	3.74	$10^{-1}_{0.95}$	0.05	0.05	19.5	16.3 IaS
6.	IaS WT + IaS DB	1.60	0.75	0.60	2.0	0.74	0.50	5.62	$10^{-1}_{0.99}$	0.01	0.01	80.9	67.4 IaS

*) γ - bulk density in g/cm^3; H_{ai} - humus content in soil (after Tyurin) in per cent;

**) z_i - $I_{(Q)}/I_n$, where $I_n = 0.90$ bit;

***) $N_y = z_e/z_i$, where z_e - information value of one standard influence ($z_e = 1$);

****) $r_{mb} = N_y/N_{sa}$, where N_{sa} - the character of SaS influence ($N_{sa} = 1.2$ rel. ind.) or $r'_{mb} = N_{sa}/Ny$ as the soil condition is getting better.

PREDICTION OF TIME CONSTRAINTS FOR MACHINERY SELECTION PURPOSES - FIELD WORKDAYS FOR TILLAGE AND HARVESTING OPERATIONS

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ABSTRACT

Calculated values of soil moisture content are used to predict the number of fields workdays. A daily soil moisture budget is constructed and various factors governing the daily fluctuations of soil moisture are identified and modelled.

A good agreement between measured and predicted data was obtained when the model was tested against the actual data which were collected for a period of four years on some Scottish soils both fallow and grass covered.

Field workdays were identified using the lower plastic limit and 1.4 mm daily rainfall as the workability critera. The final model was run using meteorological data for the past 25 years at the Bush Estate, Midlothian, Scotland and field workdays were predicted by applying a probabilistic concept. The final results were tabulated on a monthly basis for three different soil types. A 75% probability level was found to be an acceptable risk level with most farmers. The sensitivity analysis showed that the model was sensitive to changes in the soil moisture and rainfall criteria at a varying degree depending on the soil type and month of the year.

A labour and machinery Scheduling chart was devised using this data together with the crop timeliness model.

INTRODUCTION

Dwindling profit margins have forced the farmers and farm managers to re-examine the cost structure of their enterprises and reduce the production costs wherever possible. Low input farming is gathering momentum and serious consideration is being given to the reduction of the fixed costs. Power and machinery jointly represent the largest single item of the fixed costs on an arable farm therefore, selection of an optimum machine size and efficient use of the selected system are two important steps towards the reduction of the fixed costs.

To select an optimum machine size, the adverse economical effects of large machines both in the forms of higher capital costs and excessive soil damage, should be balanced against the financial gains from the lower timeliness costs and a higher insurance against the risks of bad weather. Timeliness and capital costs are largely dictated by the time available to perform field operations therefore, any planned reduction in these costs require more detailed information on the time available for various operations and the weather risks associated with these operations.

Field Workdays and Mechanisation Systems

The computer model described here forms an essential part of a more comprehensive study of the mechanisation systems selection. (Eradat Oskoui, 1981). The function of the final model is to select a mechanisation system for an arable farm so that with a known probability level all the required operations is carried out within a pre-specified period and/or if the operation is delayed the incurred timeliness penalty is calculated. Soil moisture was found to be the most important factor affecting the size and the form of the final fleet (fig. 1). Relatively long term daily rainfall records are readily available in most countries but similar figures for soil moisture content are scarce. In these circumstances, estimated values of soil moisture content is used to determine field workdays. It is therefore crucial to choose and use an accurate model for prediction of the daily variation of the soil moisture content.

SOIL MOISTURE STATUS MODEL

A prediction of daily fluctuations of soil water level can be obtained from weather variables by the existing soil moisture models. The accuracy of the predicted results from these models vary according to the complexity and accuracy of the methodology used. These models are based on the general soil moisture balance equation but they differ in the calculation of individual elements of the basic equation (evaporation, drainage and runoff). Several theories such as some for evaluating evaporation, are overcomplex for application in areas where only limited meteorological data is available, whilst the estimation of drainage in the mathematical models for predicting soil moisture level is often based on the over-simplified concept of constant flow which bears little relation to the actual fluctuations in soil water movement.

To overcome some of these limitations, a model for predicting the moisture status of unsaturated soils has been developed in which the estimation of drainage is based on the current soil water status and hydraulic conductivity (Witney, Eradat Oskoui and Speirs 1982).

The soil water balance equation used in this model is a simplified version of the equation proposed by Krimgold (1954) for predicting the moisture status of a given soil segment of a given depth, h. For the purpose of this study a 300 mm depth was chosen to represent an average ploughing depth and the following equation was used:

$$m_h = m_p + P - R - D - E \qquad \ldots (1)$$

where: m_h is soil moisture content of the segment h mm deep , m_p is soil moisture content on previous day , P is daily precipitation , R is surface runoff, D is drainage and E is evapotranspiration all in mm.

This equation provides a revised soil moisture status on a cumulative basis by adjusting the moisture content on the previous day to take into the account the current soil moisture gains and losses.

A procedure suggested by Hartman et al (1960) and later revised by Knisel et al (1969) was used to calculate surface runoff. Surface runoff is calculated by proportioning the precipitation taking into account the antecedent precipitation status.

Drainage is the most important component of the soil moisture balance equation for the soils and geographical area for which this study is carried out. An equation was developed in accordance with Darcy's law and a proposal by Black et al (1969) and soil water flux as sub-surface drainage was related to simple soil physical properties (Eradat oskoui 1981). The final form of the equation calculates the daily drainage from the values of soil moisture content and hydraulic conductivities at saturation and field capacity as follows:

$$D = K_{fc}(m_p/m_{fc})^{\alpha} \qquad \ldots (2)$$

where : $\alpha = (\ln K_{sat} - \ln K_{fc})/(\ln m_{sat} - \ln m_{fc})$

K_{sat} and K_{fc} are hydraulic conductivity at saturation and field capacity, respectively (in mm) and m_{sat} and m_{fc} are the soil moisture contents at saturation and field capacity, respectively (in mm).

Daily values of the evapotranspiration was calculated from the estimated values of potential evaporation from open water surface, by using Thornthwaite's formula(1984). Potential evaporation was calculated from the values of mean monthly air temperature and then adjusted to soil dryness, surface cover, length of day and existence of rain by means of a procedure suggested by Pierce (1966) to calculate the actual evapotranspiration.

The model was applied to some of the typical Scottish soils described by Ragg and Futty (1967). The results were compared with actual values of the soil moisture content measured by the author and The Soil Survey Of Scotland (1980) over a period of 4 years. For 10 investigations with a total of 820 data points, spanning periods of up to a year, correlation coefficients range from 0.990 to 0.999 (table I).

TABLE I **Correlation analysis of predicted and experimental values of soil moisture content.**

Code No.	Soil series	Type of cover	Year	No. of measure-ments	Regression coefficient	Standard error	Correlation coefficient
DG 72	Darvel	Grass	1972	52	0.9707	0.0189	0.990
DG 74		Grass	1974	51	0.9808	0.0131	0.996
DG 76		Grass	1976	49	0.9823	0.0103	0.997
MG 72	Macmerry	Grass	1972	51	0.9930	0.0138	0.995
MG 74		Grass	1974	52	0.9214	0.0104	0.997
MG 76		Grass	1976	46	0.9594	0.0147	0.995
MG 78		Grass	1978	133	1.0132	0.0084	0.996
MB 78		Fallow	1978	134	0.9922	0.0038	0.999
WG 78	Winton	Grass	1978	125	0.9785	0.0076	0.996
WB 78		Fallow	1978	116	1.0082	0.0053	0.998

WORKABILITY CRITERIA

Two different types of workability criteria were adopted namely, variable and fixed criteria depending on the ultimate use of the predicted results.

Variable criteria is used when the predicted results were to be used by the machinery selection program (Eradat Oskoui 1981). In this method the soil workability criterion for tillage work is chosen by maximising the draw bar pull produced by the tractor and minimising the draft required for cutting the soil of a given moisture content. The effect of timeliness and compaction penalty is also taken into the account. In practice this is done by the farmer when he decides to plough at a slightly wetter conditions in difficult years in order to get the crop in with the knowledge of the fact that he may cause sometime irreparable damage to the soil therefore altering the workability criterion and extending the number of days available for the field work. Or alternatively, he may wait sometimes weeks in order to plough in ideal soil condition risking high levels of timeliness penalties. As all these decisions are based on the economic considerations, the model uses economical constraint to obtain a soil workability criterion. Various levels of field capacity were used as workability criteria to predict days available for field work using an optimization method. Then the most suitable criterion is chosen for a given soil type, tackle size, operating conditions (speed) and crop type (Eradat Oskoui 1981).

Fixed criterion is adopted for cases when the data is to be used in isolation. In this case one or two criteria are used to predict the number of available days for field work at various probability levels. Lower plastic limit is used in conjunction with a certain level of rainfall to identify a day being as a workday or a nonworkday. Ideally, the soil should not be worked at a moisture content exceeding the lower plastic limit but, in difficult years slightly wetter conditions is tolerated in order to gain a few more work days to minimize the timeliness penalty.

FIELD WORKDAYS

The model was used to predict the number of days available for field work for the Bush Estate, Penicuik, Midlothian, Scotland. The lower plastic limit and 1.4 mm rainfall were used as workability criteria and the results are presented in table II for three soil types (light, medium, heavy) and 75% probability (LPL) level. An additional prediction of the days available was made using a slightly wetter criterion of 2% above the lower plastic limit (Table II, LPL+2%). This had a marginal effect on the results from the light soils (maximum 5%) whilst producing a considerable increase in the number of workdays (up to 40%) specially for the wetter months of the year. This sensitivity of the model for varying the soil moisture criterion became insignificant outside the range of ± 5% for heavy soils and ± 2% for light soils.

Sensitivity analysis of the model for varying rainfall criterion showed no change in the predicted number of workdays when values of greater than 1.4 mm of rainfall were used. Up to about 30% reduction was noted in the number of days available when 1.3 mm rainfall criterion was adopted. This arbitrary figure was obtained from McGechan and Gilasbey's (1986) work. They arrived at that figure by analysing the results of their experiment in which they recorded the number of days available for combining in the same area for which soil workday program was run.

TABLE II. **Field workdays for three soil types and 75% probability level for soil moisture content not exceeding the lower plastic limit and 2% above the lower plastic limit.**

Month	Number of Field Workdays					
	Light Soil		Medium Soil		Heavy Soil	
	LPL	LPL+2%	LPL	LPL+2%	LPL	LPL+2%
January	24	25	18	23	12	19
February	23	24	17	22	12	19
March	24	25	18	23	15	20
April	25	26	19	24	17	21
May	26	27	22	25	20	22
June	26	28	24	26	24	24
July	27	27	26	27	26	26
August	26	26	25	26	24	26
September	25	26	23	24	20	23
October	23	25	19	22	17	21
November	22	25	18	22	17	21
December	23	25	18	22	14	20

The data presented here were suggested to be used for soil engaging works such as ploughing, cultivating, drilling, root harvesting and earth moving. On these days the soil is also trafficable therefore, suitable for works such as baling, straw carting, forestry work and military activities. Initially, grain harvesting was excluded from the list of operations which can be carried out on these days (Oskoui 1986) but the above analysis indicated that these data can be applied to harvesting operation as well as the soil engaging ones. Using combined criteria of soil moisture and rainfall as opposed to rainfall alone has an added advantage of identifying the days in which the soil is trafficable as well as being suitable for the combining operation.

PROBABILITY LEVELS

A level of 75% is given in table II. which is recommended for long term machinery and labour planning: it indicates the number of workdays available in 18 years out of 24. In the remaining years the availability of fewer workdays is compensated by extra overtime, employing more casual labour or contractors to complete the operation instead of incurring the extra cost of purchasing larger machinery in order to obtain a higher probability of completion of the operation.

APPLICATION OF DATA

The data produced by this program can be used in many ways. By running the program and using data from various climatological stations throughout the country a workday map can be produced. An immediate application of this data is the construction of a labour/machinery scheduling and management chart. Workdays and timeliness penalties data are used to produce a graphic model for annual scheduling of labour and machinery in an agricultural enterprise. This model can contain workday and timeliness penalty data for as many geographical area and crop type as required. This is a major advancement from other models which contain only one set of workday data and no timeliness information. Figure 2 shows a sectional representation of this chart.

The labour and machinery management and scheduling chart, the description of which is given elsewhere (Eradat Oskoui 1988) is used as an advisory and management aid when:

- analysing the existing mechanisation system of a farm;
- predicting machinery requirement of a newly established farm;
- considering the inclusion of a new crop in the rotation;
- considering to take on more land;
- deciding whether to use contractors or contract out machinery,

or as a teaching aid to:

- increase the students awareness of the interactions of the weather, machinery and timeliness of operations;
- evaluate the effects of long term and short term decisions on the size and operation of the farm machinery and equipment;
- evaluate the effects of varying risk levels on the final structure and cost of agricultural mechanisation systems.

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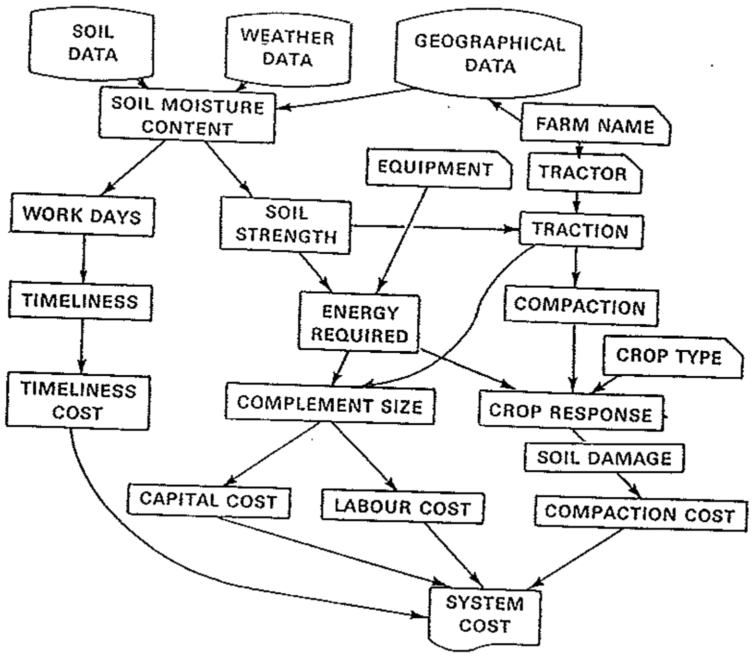

Fig. 1. The effect of soil moisture content on the various elements and the final cost of agricultural mechanisation systems.

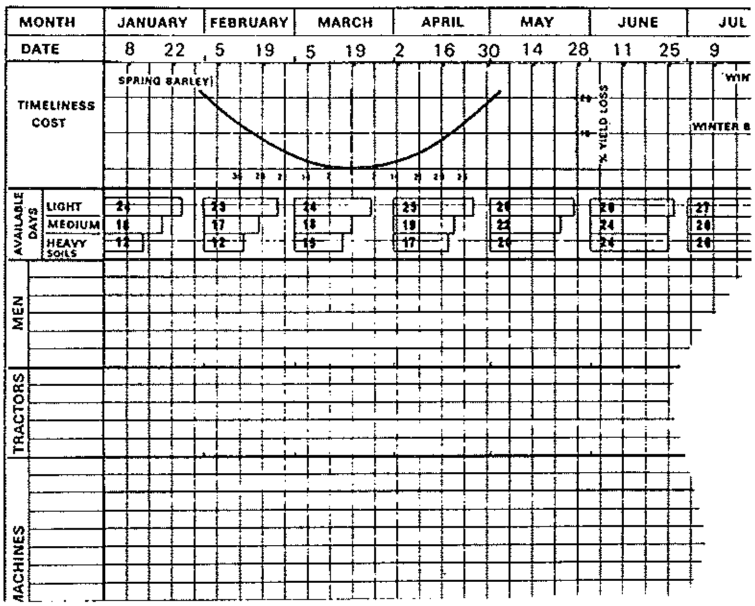

Fig. 2. A sectional representation of the labour/machinery scheduling and management chart.

EFFECTS OF INDUCED COMPACTION IN SOIL WATER BALANCE AND CROP YIELDS ESTIMATED WITH A DETERMINISTIC SIMULATION MODEL

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ABSTRACT

The SIBIL model, simulating soil water balance and crop yields, is presented. It was developed from similar existing models, and it is used in Romania for various purposes. Part of the mode, referring to root system development is affected by physical properties of compacted soils, is emphasized. Simulated grain maize yields, for four different sites and for two induced compaction treatments, were used for model validation. The model was used to separate various mechanisms involved in soil compaction - crop yields relationships, and relative effects of decreases in root front depth and in soil water supplying ability were found to be different for various sites.

INTRODUCTION

Much progress has been accomplished during recent years in the field of mathematical models simulating soil moisture regime and its effect on crop biomass accumulation. Some of these models are SWATR (Feddes et al., 1978), ARIDCROP (Van Keulen, 1983), CORNGROW (Tscheschke and Gilley, 1979), CERES (Ritchie and Otter, 1984). One way to use such models is related to the estimation of the effect of changes in soil physical properties on soil moisture content and crop yields. Using these models in the field of soil compaction requires development of formal expressions relating root parameters to water uptake to soil physical parameters (Taylor and Bruce, 1968; Huck and Hillel, 1983; Jakobsen and Dexter, 1987).

This approach has been used, as a first approximation, in an earlier paper (Simota et al., 1986). Here, further development of the model, as adapted to soil compaction studies, is presented, and results of new field experiments on various soils are used for model validation.

DESCRIBING THE MODEL

General outline of the model

As in most other simulation models of this kind, soil water balance in the presence of a crop and water uptake by roots were taken into consideration adding to the equation of continuity a sink term (S ψ ,z):

$$\frac{\partial w}{\partial \psi}\frac{\partial \Psi}{\partial t} = \frac{\partial}{\partial z}\left[K(\Psi)\frac{\partial \Psi}{\partial z} - K(\Psi)\right] - S(\psi,z) \qquad (1)$$

As determined by (1), water uptake is a local term and, to get total uptake for a specified time, it has to be integrated for depth z.

To determine the sink term and to solve (1), separation of variables yielded:

$$S(\Psi,z) = Sm(z) \cdot f(\Psi) \qquad (2)$$

$f(\psi)$ in (2) represents the decrease in water uptake by roots resulting from changes in soil water matric potential w. It was approximated according to Feddes et al. (1978), which implies dividing the matric potential range into three regions, separated by three critical potentials (ψ1, ψ2, ψ3).

The other variable in (2), Sm, represents maximum soil water supplying ability, and it depends upon both soil moisture properties and root system characteristics. In this model, Sm is studied considering a root as a cylindrical tube, and it is calculated according to Steinhardt et al. (1982):

$$Sm(z) = \frac{4\pi}{\ln[2Vr(z)]} \cdot Le(z) \cdot K(\Psi l) \cdot \frac{\Psi l}{n-1} \qquad (3)$$

where n is the exponent in an equation of the Brooks-Corey type.

In (2), Vr, the volume of soil not filled in by roots, and Le, the effective length of roots, were estimated by:

$$Vr(z) = 1 - \frac{mr(z)}{\rho} \qquad (4)$$

$$Le(Z) = \frac{mr(Z)}{\pi \rho r^2} \qquad (5)$$

where r is root radius, ρ root density, and mr local root biomass.

Depth of the root front resulted from an integration of the advancing speed of the root front, vr:

$$vr = vp \cdot RP^{-\gamma} \qquad (6)$$

where vp, the potential advancing speed, and γ are parameters from current literature (for maize vp is 2.5 cm/d, and γ 1.12), and RP is soil resistance to penetration.

Determining root parameters of the model

Two alternative ways to determine root biomass were used, and the corresponding algorithms are suggested.

The first algorithm is to be used for soils with resistance to penetration slightly variable within the profile. In agreement with Nerpin and Sarojan (1976), the cumulative root biomass Mr was considered to have a depth distribution according to error functions:

$$Mr(z) = \alpha\,[\mathrm{erf}(z/zr) - \mathrm{erf}(zo/zr)] \qquad (7)$$

As a consequence:

$$mr(z) = \frac{\partial Mr(z)}{\partial z} \cdot dz \qquad (8)$$

The second algorithm to calculate root biomass was developed from that suggested by Jakobsen and Dexter (1987),and it is to be used when layers with excessive resistance to penetration are present within the soil profile. Seminal roots deviated due to the presence of such layers, non deviated seminal roots, and lateral roots were treated separately in this algorithm, total local root biomass being:

$$mr(z,t) = \int_{to}^{tr} [DMn(z,t) + DMd(z,t) + DMl(z,t)] \cdot dt \qquad (9)$$

where DMn, DMd and DMl are biomasses of the above three types of roots. Compaction affects mainly the first type of roots, and this was expressed by:

$$Nd(z) = (1 - \mu) \cdot Nn(z) \Big|_{z=zr(t)} \tag{10}$$

where Nd and Nn are numbers of seminal roots, deviated and respectively non deviated (for maize, Nn(zo) is taken as 4), and μ is:

$$\mu = \exp \left[-\gamma \frac{\partial RP(\Psi, z)}{\partial z} \cdot dz \right] \Big|_{z=zr(t)} \tag{11}$$

where RP is resistance to penetration and γ a parameter (0.35 for maize).

Determining soil parameters of the model

Soil data used as input in the model are:

- soil moisture characteristic;
- saturated hydraulic conductivity;
- resistance to penetration, standard laboratory test, as determined at a soil moisture content equal to 50% of the air entry value (Canarache, 1965);
- bulk density;
- clay content.

The three critical soil moisture matric potentials suggested by Feddes et al. (1978) were determined using the soil moisture characteristic:

- $\Psi 1$ as the matric potential corresponding to an air content of 0.05 for well structured soils, and of 0.10 for weakly structured soils (Bakker, 1978);
- $\Psi 2$ as the intersect of the moisture characteristic curve with a straight line starting from (w=0, pF=2.18) and describing an angle of $13^{o}7$ with the x axis (Voronin, 1980);
- $\Psi 3$ as pF = 4.2

Unsaturated hydraulic conductivity was determined using a method suggested by Voronin (1980), based on the Brooks - Corey model.

Resistance to penetration as affected by soil moisture content was calculated using a model developed from earlier experimental research. It has the advantage to avoid experimental determination of parameters for each soil in part. The model is:

$$lg(RP(w)) = lg(cp) + s - 0.37.C^{0.051}.BD^{3.12}.(1.7-lg(we)) \tag{12}$$

where cp is the constant of the specified type of penetrometer used, s is the standard laboratory resistance to penetration, C is clay content, BD is bulk density and we is moisture content expressed as a fraction of the air entry value. When standard laboratory resistance to penetration tests are not available, s may be calculated from:

$$s = -0.07 + 0.02 \cdot C + 7.53 \cdot lg(BD) \tag{13}$$

VALIDATING THE MODEL

The above model was validated using data from four 1986 experimental fields with induced soil compaction. Compaction was done in spring, before sowing of maize, by 10 wheel-by-wheel tractor passes. Some of the soil and climate characteristics of the experimental sites are as follows:

Site	Soil	% Clay* <0.002 mm	Drainage	Rainfall**+ irrigation	Average temp. **
Valu lui	Chernozem	32 / 29	Well drained	110 + 240	17.7
Simnic	Reddish-brown	25 / 41	Moderate	283	19.1
Oradea	Argillic brown	31 / 40	Moderate	347	16.9
Livada	Albic Luvisol	14 / 35	Imperfect	355	18.0

* Topsoil / lower soil horizons
** Vegetation period (April 1 - September 30, 1986)

Experimental and simulated soil water matric potentials (second part of the vegetation period, 0-40 cm soil depth) are compared in Figure 1A. Differences were less than 5%, which is of the same order of magnitude as those accounted for by spatial variability.

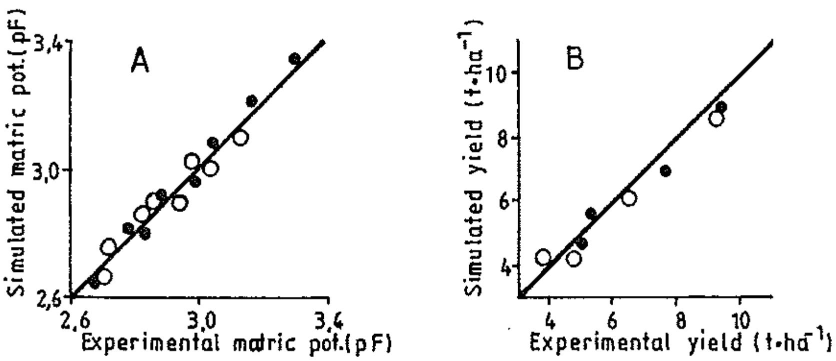

Figure 1. Comparasion of experimental and simulated soil water matric potential (A) and grain maize yield (B) (four experimental sites, 1986); (●) Not compacted and compacted (O)

Figure 1B compares experimental and simulated grain maize yields, and it shows differences less than 15%. There was a trend for simulated yields to be somewhat greater than experimental ones for less productive sites, and somewhat smaller for more productive sites.

Decreases in yields due to induced soil compaction, as explained by changes in soil moisture properties or by decreases of root front depth, are shown in Figure 2. The relative weight of these two mechanisms involved in compaction was different for various soil and climate conditions: on the Argillic Brown soil at Oradea ca.70% of the decrease in yield was explained by changes in soil moisture properties, while on the Reddish-Brown soil at Simnic ca.60% was explained by decrease in root front depth.

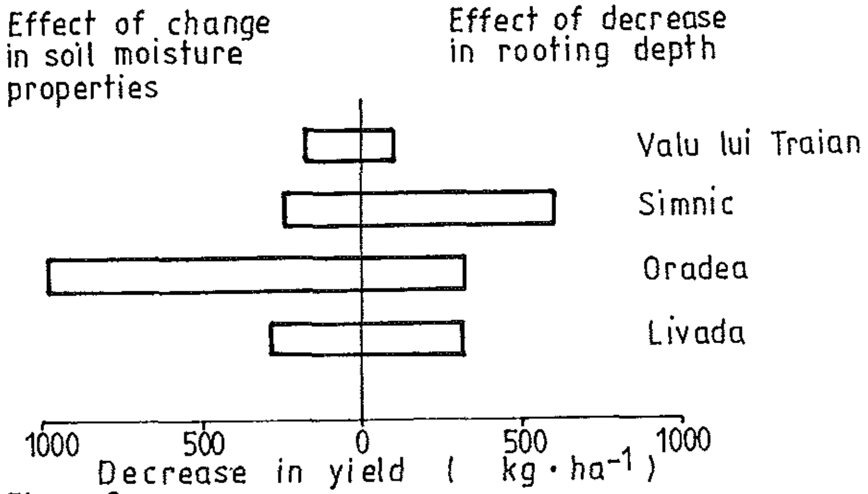

Figure 2.
Decrease in simulated yield of grain maize (1986) following induced soil compaction, as explained by changes in soil physical properties and by decrease in by rooting depth

CONCLUSIONS

1. The simulation model developed in this paper accurately predicted soil water matric potential, crop yields, and effects of induced soil compaction on soil moisture properties and on root front depth.

2. Relative influence on crop yields of changes in soil moisture properties and of decrease in root front depth could be studied using this simulation model, and it was different for various soil and climate conditions.

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FIELD EXPERIMENTS AND MODELLING OF SOIL COMPACTION WITH PARTICULAR REFERENCE TO VEHICLE WEIGHT AND GROUND PRESSURE

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ABSTRACT

Experimental results from a series of field experiments support the theory that compaction at depth is largely dependent upon wheel load and that ground pressure largely effects compaction near the soil surface. The depth of a wheel rut is largely dependent upon the ground pressure and thus gives little indication of the compaction at depth. Briefly described is a simple, numerical compaction model which extends the value of field experiments by predicting changes in dry bulk density resulting from the passage of various arrangements of wheels.

INTRODUCTION

This paper briefly outlines a series of field experiments designed to investigate the relative importance of vehicle weight and ground pressure to the process of soil compaction. Full details of the experiments and of the findings are available elsewhere (Smith and Dickson, 1988). Also briefly described is a simple numerical model which may be used to extend the results of field experiments, by predicting the relative degrees of compaction caused by various wheel arrangements, and to assess the relative importance of each wheel or soil variable in the compaction process. The model is described in greater detail elsewhere (Smith, 1985) and is available, along with full documentation, from the author.

FIELD EXPERIMENTS

Objectives

The objectives of the series of four field experiments were to:

i) investigate, for field soil conditions, theoretical predictions that increases in wheel load result in significant increases in soil compaction at depth but have less effect near the soil surface, whereas increases in mean ground pressure result in significant increases in soil compaction near the soil surface but have less effect at depth, and

ii) to examine whether a self-propelled vehicle carrying a low payload or a tractor-drawn vehicle carrying a high payload, both purpose-built to minimize soil compaction, offer any advantages over conventional vehicles carrying the same payloads.

Compaction treatments and field sites

The first three experiments were designed to meet the first objective and investigated i) the effect of varying mean ground pressure at a fixed wheel load, ii) the effect of varying wheel load at a fixed mean ground presure, and iii) the interaction between mean ground pressure and wheel load. Single wheel loads between 10 and 31 kN and mean ground pressures between 41 and 117 kPa were obtained by ballasting and adjusting the tyre inflation pressures of single-axle trailers.

The fourth experiment, designed to meet the second objective, investigated the compaction resulting from the passage of:
i) a self-propelled, 2WD, low-weight sprayer and a conventional, 2WD tractor with mounted sprayer both carrying a nominal payload of 8 kN,
ii) a five-axle, track-laying trailer and a single-axle, wheeled-trailer both carrying a nominal payload of 60 kN and drawn by a 2WD tractor, and
iii) an unladen 2WD tractor as a reference vehicle.
All four experiments were performed on a loosened sandy loam soil and the fourth experiment was also performed on a loosened loam soil. In the first three experiments, the single-axle trailers were drawn by a 3 m-wide-track tractor, at approximately 5 km/h, such that one wheel passed down the centre of the allotted plot whilst the other wheel passed down one of the tramlines used by the tractor. In the fourth experiment the vehicles (and trailers) were driven, at a nominal 6.5 km/h, with their off-side wheels passing down the centre of their allotted plots.

Measurements

To estimate the mean ground pressure (wheel load/contact area), white powder was spread liberally on the prepared soil around the boundary between the tyre and the soil and then, having removed the wheel by reversing the vehicle, the squares marked a rigid, transparent plastic sheet placed over the trace were counted.

Soil compaction was assessed by measuring i) soil bulk density using a high-resolution gamma-ray probe, ii) soil cone resistance, using a recording penetrometer, and iii) rut profiles using a needle relief meter. Bulk density and cone resistance measurements were made along the centre line of each plot, down to 0.51 m depth, before and after the passage of the vehicles. Unreplicated but extensive measurements were also made up to 0.6 m either side of the centre line in two of the experiments.

Discussion of results

Space allows only a selection of the more important results to be reported here. The variations of bulk density with depth before and after the passage of wheels supporting two loads at two ground pressures are shown in Fig. 1. The variations are presented according to the method of Henshall and Smith (1988; Smith, 1987) which removes the difficulties of interpretation caused by wheel ruts of different depths. In this method bulk density measurements are used to trace vertical soil movements to allow comparisons between compaction treatments to be made on soil elements which derive from the same depth in the undisturbed profile, irrespective of their depths in the compacted profiles. The changes in bulk density, due to the passage of a vehicle, are calculated for the soil at the depths of the initial (before passage) measurements. These changes are then added to, and plotted alongside, their respective densities (at the same depth) thereby removing the effect of the ruts. It may be seen that in the upper soil layers (0 - 0.2 m) the increrases in bulk density are dependant mostly upon ground pressure and are unaffected by wheel load, whereas at depth (0.3 - 0.5 m) the increases are dependant mostly upon wheel load and are unaffected by ground pressure. It was also found that an increase in wheel load, whilst maintaining similar ground pressure, resulted in a greater lateral extent of soil compaction. These results were supported by the other bulk density measurements and were generally reflected by the cone resistance measurements, although there were anomalies. The depths of the wheel ruts were influenced by the ground pressure primarily and thus they did not reflect the greater compaction at depth resulting from the greater wheel loads.

The variations in soil bulk density with depth before and after the passage of the five vehicles are shown in Fig. 2 using the method of Henshall and Smith. The low-weight sprayer produced only about half the increase in density of the other vehicles, amongst which there were smaller differences, and the heaviest vehicle, the tracked-trailer (100 kN), produced the greatest compaction at depth even though its mean ground pressure was low (25 kPa). These results were fully supported by the cone resistance measurements. The low-weight sprayer produced the shallowest and smallest (lowest cross-sectional area) ruts and the trailers produced the largest ruts. The ruts produced by the tracked-trailer were shallower than those of the wheeled-trailer, and in this respect the tracked-trailer may be considered to have had a practical advantage in minimizing soil damage, but they also did not reflect the increased compaction at depth due to its weight.

Compaction model

The model predicts changes in soil bulk density arising from changes in soil stresses which result from transient wheel loads. The depth of soil to be modelled is divided into elemental layers and the spherical stress increase at

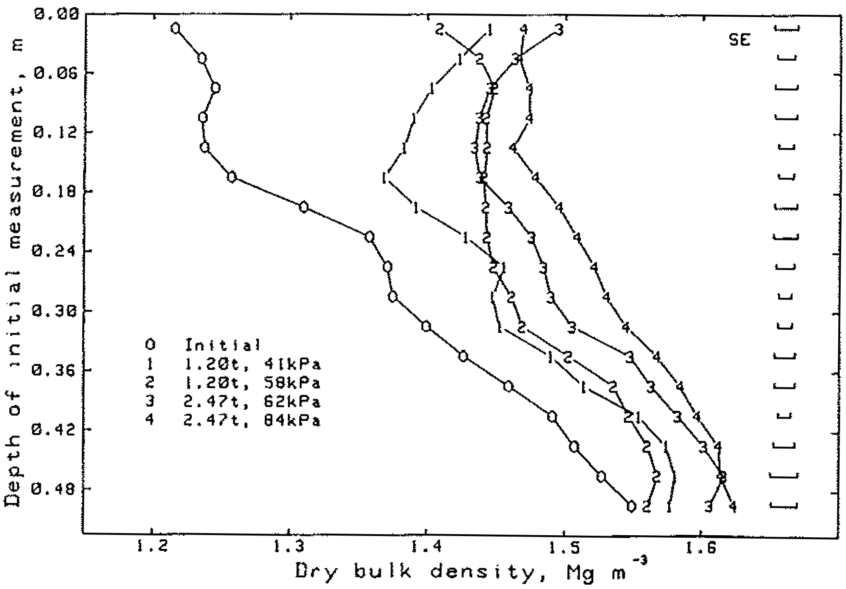

Fig. 1 Increases in soil dry bulk density with depth below initial measurement due to the passage of two wheel loads at two ground pressures.

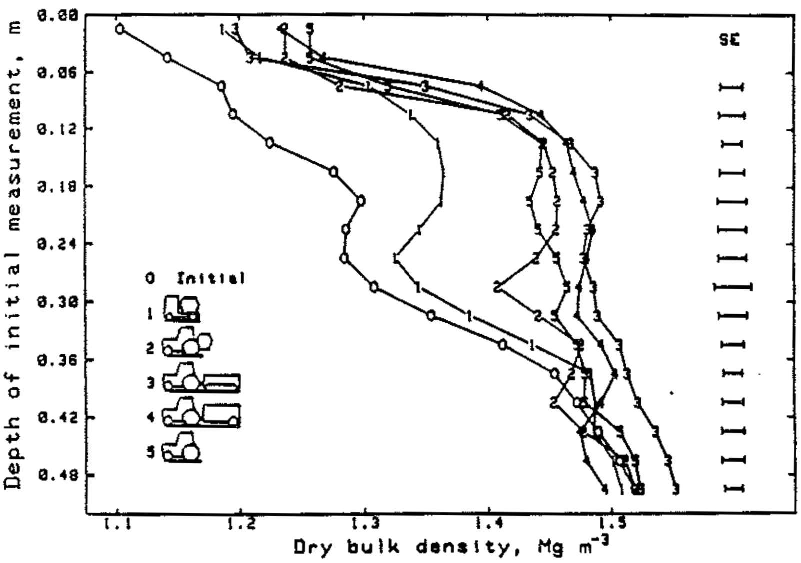

Fig.2 Increases in soil dry bulk density with depth below initial measurement due to the passage of five vehicles.

the centre of each layer, below the centre of the wheel load, is estimated. The model procedure then estimates the resulting soil volume changes in each layer from the isotropic stress-strain relationships of the soil. Currently, suitable data are available only for a sandy loam soil.

The validity of the model was assessed by predicting the compaction caused by the five vehicles described above. The model overpredicted the densities just below the bottom of the ruts but performed satisfactorily at all other depths down to 0.5 m. The overpredictions may be attributed to soil loosening by the driving wheels and to surface irregularities due to tyre lugs for which the model does not account.

Although the model may be unable to make accurate predictions of the absolute soil bulk density changes due to the passage of wheels in every instance even if accurate input data are used, its value lies in its ability to rank vehicles or wheels in order of their compacting potential and to assess the relative importance of given wheel and soil variables in the compaction process. For example, the predicted compaction for the passage of wheels supporting 10 and 30 kN loads, each at a mean ground pressure of 100 kPa, are shown in Fig. 3. Although the initial soil dry bulk density and water content profiles are atypically uniform, they allow for comparisons of wheel load effects without confusion from minor variations in soil conditions. It may be seen that the compaction produced by the 30 kN wheel load is large in the subsoil but that it may be reduced substantially by reducing the wheel load alone without reducing the ground pressure.

CONCLUSIONS

1) Field measurements of soil dry bulk density largely substantiated theoretical predictions that increasing wheel load results in increased compaction at depth, both below and either side of the rut centre line, but has less effect near the soil surface, whereas increasing the mean ground pressure results in increased compaction near the soil surface but has less effect at depth.
2) The low-weight, low ground pressure sprayer produced significantly less compaction than a conventional tractor with the same payload but the low ground pressure, tracked-trailer produced appreciable compaction at depth due to its high gross weight.
3) Rut dimensions alone do not give an indication of the distribution of soil compaction with depth.
4) Soil compaction modelling can i) extend the results of field experiments by predicting the relative distributions of bulk density with depth due to the passage of vehicles, and ii) assess the relative contributions made to the compaction process by changes in wheel and soil variables.

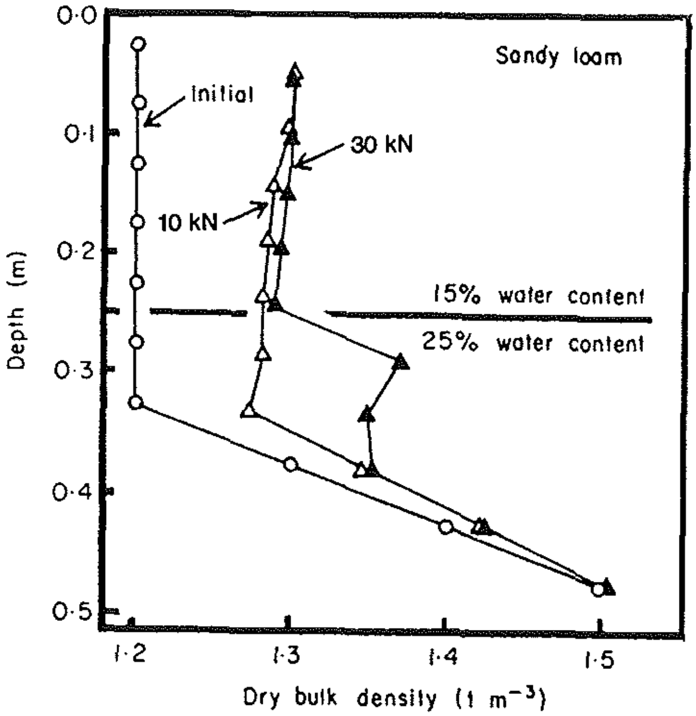

Fig. 3 Predicted increases in soil dry bulk density due to the passage of 10 kN and 30 kN wheel loads, each at a mean ground pressure of 100 kPa.

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MODELCOMPUTATION OF SUBSOIL STRESS DISTRIBUTION AND COMPACTION DUE TO FIELD TRAFFIC

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ABSTRACT

To evaluate the effect of field traffic on the density of the subsoil under different conditions of loading and compactability (depending on soil type and moisture conditions) the numerical model SOCOMO has been developed. SOCOMO calculates stress distributions under wheels. Calculations of the principal stress distribution caused by a wheel loading agree well with measurements in the field. By means of techniques originally developed for air-photography two-dimensional density distributions from traffic experiments on a sandy soil have been photographed and digitized. The calculated and measured depth of the area where plastic deformations occur, is almost the same and reaches till 80 cm.

INTRODUCTION

Nowadays more than 65% of arable land in the Netherlands is used for growing maize and root crops like potatoes and sugar beet. Under sometimes wet soil conditions up to 60 ton.ha-1 has to be harvested. In areas with intensive livestock farming slurry is brought onto maize fields with tanks with capacities up to 30 ton. These developments have considerably increased the risk of soil compaction. Soil compaction mainly concerns the subsoil, because the topsoil can be loosened every year, but compaction of the subsoil can only be remedied with great effort. Subsoil compaction is primarily observed in the Netherlands on light sandy loam and sandy soils. This kind of soil is mostly susceptible to recompaction and the scarce continuous pores in the primary compacted layer are lacking in the recompacted layer (Kooistra et al. 1984).

The risk of soil compaction depends on initial bulk density, moisture content of the soil, the inflation pressure and width of the tire and the wheel load. To study the effect of heavy vehicle traffic during different soil and load conditions, the soil compaction model SOCOMO (SOil COmpaction MOdel) is being developed (Van den Akker and Van Wijk, 1987). The model calculates the stress distribution in the soil caused by a horizontal and vertical wheel load. With the aid of relationships between these stresses and bulk density the stress distribution can be converted into a density distribution.

To verify the model controlled traffic experiments have been executed in the field. With pressure transducers the vertical stresses at the interface of the loose topsoil and the firm subsoil have been measured. Deformations and compactions have been measured by photographing before and after the wheel passage a vertical point grid placed in the subsoil.

PRINCIPLE OF THE MODEL

The model is based on the theory of Boussinesq (1885), describing the distribution of stresses in a homogeneous isotropic semi-infinite solid mass due to a force applied on a point on the surface of that mass. On any volume element in the semi-infinite solid vertical, horizontal and tangential normal stresses and vertical and horizontal shear stresses are operative (Fig. 1)

Fröhlich (1934) proposed to set the Poissons' ratio on 0.5 in the formulas of Boussinesq. This means that no change of volume of the soil occurs. Nevertheless the influence of this assumption on the results is small. Fröhlich also introduced a concentration factor (ν) in Boussinesq's formulas to account for the tendency of the soil to concentrate the stresses around the load axis. The resulting equations for the stresses are:

$$\sigma_z = \frac{\nu P}{2\pi r^2} \cos^{\nu} \theta$$

$$\sigma_h = \frac{\nu P}{2\pi r^2} \cos^{\nu-2} \theta \sin^2 \theta$$

$$\sigma_t = 0$$

$$\tau_z = \tau_h = \frac{\nu P}{2\pi r^2} \cos^{\nu-1} \theta \sin \theta \qquad (1)$$

where: σ_z, σ_h, σ_t = vertical, horizontal and tangential stress respectively
τ_z, τ_h = vertical and horizontal shear stress
P = vertical point load
r and θ = polar co-ordinates

The value of ν is greater when the soil is more soft. Koolen and Kuipers (1983) give values of ν of 3,4 and 5 for a hard, normal and soft soil respectively. When ν = 3 the formulas of Boussinesq are obtained with a Poissons' ratio of 0.5. Because the equations (1) are based on a linear elastic material, it is possible to superpose the stresses on a certain

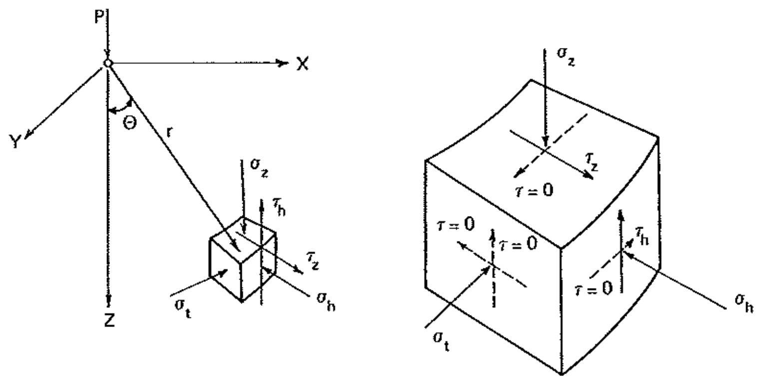

Fig. 1. Composition of stresses acting in a volume element due to a vertical point load P on a semi-infinite solid. σ = normal stresses, τ = shear stresses, r and θ = polar co-ordinates.

soil element caused by several point loads. Of course only stresses with the same direction can be added. This is the case with the vertical stresses σ_z. The horizontal and shear stresses have to be decomposed in their x- and y-components first. By dividing the vertical stress distribution in the wheel-soil contact surface in separate point loads, it is possible to compute the stress distribution in the soil caused by a vertical wheel load. Söhne (1953) has done so for the vertical stress distribution caused by a vertical wheel load. Analogous to the vertical point load and wheel load the same procedure has been followed for the horizontal point load and wheel load. Thus all the vertical, horizontal and shear stresses can be computed in any point in the soil for each given vertical and horizontal load. In addition to the dynamic stresses due to wheel loading there has also to be accounted for the influence of the weight of the soil on the vertical and horizontal stresses. After Tschebotarioff (1951) the horizontal static stress is 0.5 times the vertical static stress. From all the dynamic and static stresses the principal stresses S_1, S_2 and S3 can be derived (Timoshenko and Goodier, 1980). The stress situation in a certain point is given by these three principal stresses.

For agricultural soil a critical state soil mechanics model has been presented by Hettiaratchi (1987). This model is the best base for the stress - volume change relationship. According to this model the volume of a soil element during plastic deformation depends on the mean normal stress $\sigma_m = (S_1+S_2+S_3)/3$ only:

$$v = \Gamma - \lambda \ln(\sigma_m) \qquad (2)$$

where Γ and λ are two soil parameters that can be derived with triaxial tests. When soil is loaded, the initial volume of the soil element is usually not a point of the line given by equation (2) and a certain deformation is necessary before the equation is valid. Subsoil deformation will not be very great generally. This complicates the stress - volume change relationship enormeously, because for small deformations volume change not only depends on the mean stress σ_m but is also related to the deviator stress *(S_1-S_3) and the main axial strain ϵ_1. Investigations to derive a* stress - volume change relationship to convert stress distributions into density distributions are in progress.

If no plastic deformation occurs, volume change will be small. The minimum magnitude of S_3 to prevent failure due to S_1 can be found from the Mohr - Coulomb equation:

$$S_3 = K_a\ S_1 - 2c\sqrt{K_a} \qquad (3)$$

where: $K_a = \tan^2 (45° - \phi/2)$
ϕ = angle of internal friction
c = cohesion

If the smallest principal stress S_3 computed with the model is smaller than S_3 calculated after eq. (3), the soil will deform until S_3 is sufficiently increased to counteract the deformation. With the model the area where plastic deformation occurs can be computed.

CONTROLLING FIELD EXPERIMENTS AND VERYFICATION OF THE MODEL

With a single-wheel tester controlled traffic experiments on a sandy soil have been carried out. The wheel load applied amounted to 32 kN. The tire was a Vredestein Special Ribbed 16.0/70-20 with an inflation pressure of 2.4 bar. With pressure transducers the vertical stresses at the interface of the loose topsoil and the firm subsoil have been measured. This procedure gives better results than measuring within a homogeneous soil mass (Schoenmakers and Koolen, 1987). The results of the measured and computed vertical stresses are compared in fig. 2. A concentration factor ν = 4 (normal soil) has been used. Vertical stresses computed with ν = 3.5 and 4.5 have been included, to show that the influence of the concentration factor on the computed stresses in this depth (22 cm) is low. The major principal stress S_1 distribution and the area where plastic deformations occur are given in fig. 3a and 3b respectively. The stresses in the rut due to the wheel load are simplyfied to a trapezoic stress distribution. According to a rule of thumb (Koolen and Kuipers, 1983) the maximum stress is 1.2 times the inflation pressure. The area where according to the computed minor principal stress S_3 is too small to prevent plastic deformations reaches to 70 cm depth (fig. 3b). The angle of internal friction ϕ = 31° and the cohesion c = 10 $kN.m^{-2}$ used were derived from triaxial tests; c is mainly determined by the negative soil moisture pressure.

To measure and visualize compaction and deformation in the subsoil due to heavy wheel traffic a sensitive method has been developed. The method makes use of a vertical point grid positioned into the soil profile perpendicular to the direction of moving of the wheel. Before and after wheel passage the point grid is photographed. Through a photogrammetric technique from air-photography the positions of the grid points before and after wheel passage can be measured and deformations and compactions computed. The deformations and the bulk densities after wheel passage are given in fig. 4a and 4b respectively. To a depth of 80 cm the measured vertical strain of the soil observed was to such extent that according to triaxial tests plastic deformation must be occured. This agrees with the depth of the computed plastic deformation area in fig. 3b.

CONCLUSIONS

The predicting of the stresses in the soil with SOCOMO is satisfactory. The computed and measured stresses at the interface of the loose topsoil and the firm subsoil agree very well. Also the measured and calculated depth of the area where plastic deformations occur is almost the same. Measured plastic deformations reached till 80 cm depth, much deeper than commonly believed. Further research to derive a good stress - compaction relationship is in progress.

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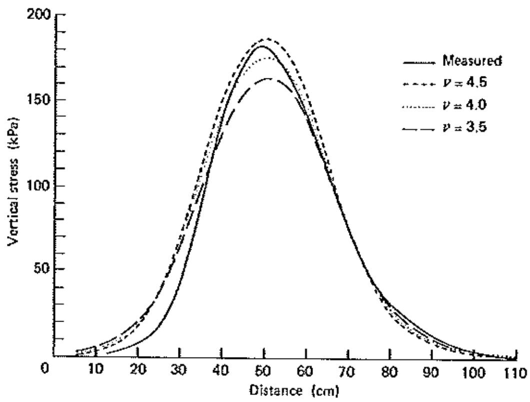
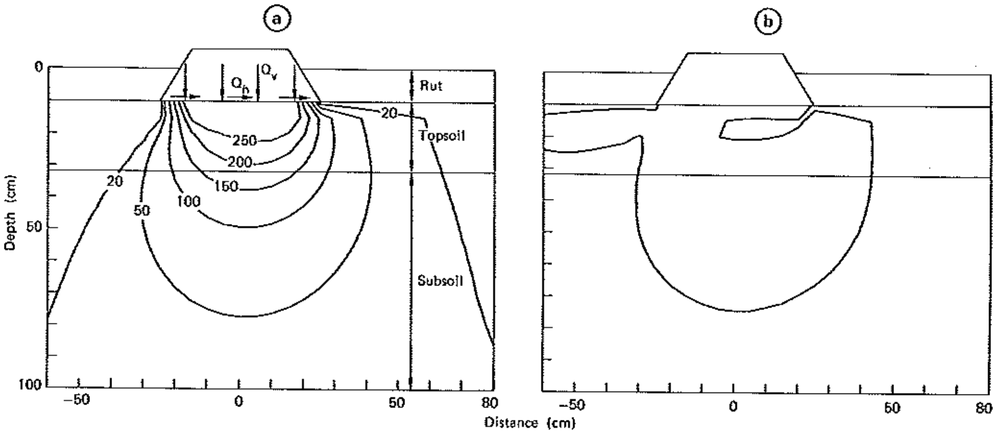


Fig. 2. Measured and computed vertical stress in the interface topsoil-subsoil. Concentration factors used 3.5, 4.0 and 4.5.

Fig. 3. Computed distribution of the major principal stress S_1 in kPa (a) and the resulting plastic deformation area (b). The wheel load is simplyfied to a trapezoic vertical (Q_v) and horizontal (Q_h) stress distribution. The concentration factor used is 4.0, the angle of internal friction ϕ = 31° and the cohesion c = 10 kPa.



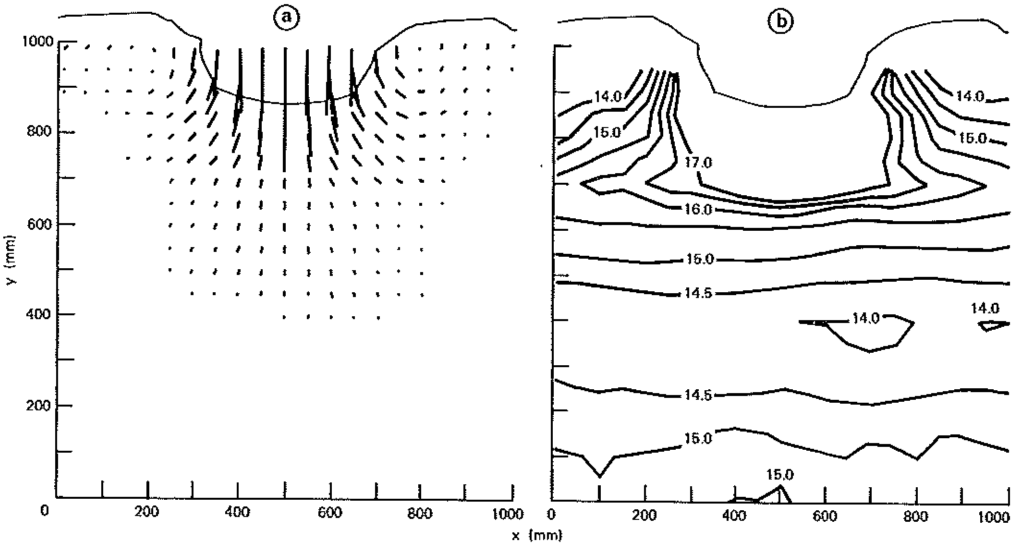


Fig. 4. Measured deformations (a) and dry bulk density distribution ($kN.m^{-3}$) (b) under a rut in a sandy soil after wheel passage.

A TEXTURAL APPROACH TOWARDS MODELLING OF SOIL COMPACTIBILITY*

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ABSTRACT

The permanence of expensive deep soil loosening actions is uncertain on at least some soil types because a measure of compactibility is not available on a routine basis. Seventy-one soil types comprising of a wide textural range and different susceptibilities to compaction were sampled. Every sample was separated in eleven particle size classes, including the 2 - 6 mm fraction. Two simple-to-use prediction models were evaluated for their ability to predict compactibility from soil textural data. Multiple regression models were fairly good to predict maximum Proctor bulk density of the sample population, but auto-correlation between the independent variables might limit extrapolation. The Gupta-Larson random packing model did a good job to predict field measured bulk density and could even identify outlier soils which is of importance for soil management decisions.

INTRODUCTION

The equilibrium compaction attained by soils is a prime determinant for decision-making on soil management techniques to create and maintain a favourable soil structure. Compaction problems, together with poor root development, has been clearly defined in the grapevine growing areas of the Republic of South Africa. However, it is often found that soils which has been deep ploughed at great expenses to a depth of 100 cm recompact unexpectedly after wetting and drying while others are more stable and compact only under compression forces. This phenomenon complicates decisions on soil management.

Considerable progress has been made to identify various soil properties and factors determining compactibility to mention only the publications of, and the literature quoted by, Van der Watt (1969), Moolman (1981), Hussain **et al.** (1985) and Gupta and Allmaras (1987). Soil texture can be expected to influence the susceptibility of soils to compaction as it plays a significant role in the development and stability of soil structure.

Various models have been employed to predict compaction from soil texture. However, according to Gupta and Allmaras (1987) there still is a need for refined calculations and validation of soil compaction models. Voorhees (1987) also stressed the need to develop a methodology to assess the susceptibility of a given soil to compact.

It is also well-known that other soil properties such as aggregate stability, organic matter content, particle shape and roughness also

*Extract from data to be submitted for a Ph.D. to the University of Stellenbosch. Promotor: Dr. J.H. Moolman affects soil compaction, but this will be dealt with in a follow-up paper. This paper reports on the prediction of bulk density for a wide textural range of soils from different regions and parent materials. The two techniques employed were the random packing model of Gupta and Larson (1979) and the statistical approach described by Moolman (1981).

MATERIALS AND METHODS

A total of 71 soil samples of 50 kg each were collected in the Western, Southern and Northwestern Cape Province to include different soil forms and parent materials. Soils exhibiting different degrees of compaction problems as well as those without problems were sampled. In ca. 50 per cent of the cases samples were taken from each horizon of a particular soil profile while for the rest either the top- or subsoil was sampled depending on the soil type, texture, root distribution and soil management history. Soils were sampled when just below field water capacity and special care was taken not to disturb natural aggregation. After sieving on a 6 mm rectangular grid, the soils were left to get air-dried.

The soils were separated into 11 particle size classes, viz: 6.00 - 2.00 mm; 2.00 - 1.00 mm; 1.00 - 0.50 mm; 0.50 - 0.30 mm; 0.30 - 0.25 mm; 0.25 - 0.106 mm; 0.106 - 0.075 mm; 0.075 - 0.053 mm; 0.053 - 0.020 mm; 0.020 - 0.0020 mm and < 0.002 mm. The mass percentage of each fraction was expressed both on a < 6 mm and < 2 mm diameter basis. The percentage spread within the three main particle size classes (< 2.0 mm) is presented in Fig. 1 and was as follows:

Clay (< 0.002 mm)	1.17 - 37.63 %
Silt (0.002 - 0.053 mm)	2.25 - 46.65 %
Sand (2.00 - 0.053 mm)	33.96 - 95.40 %

The sandgrades expressed as a percentage of the total sand fraction were, like the above textural classes, very representative for South African conditions:

Fine sand (0.25 - 0.053 mm)	9.66 - 98.16 %
Medium sand (0.50 - 0.25 mm)	1.18 - 39.18 %
Coarse sand (2.00 - 0.50 mm)	0.32 - 74.79 %

The 2 - 6 mm diameter fraction ranged from 1.9 % to 47.1 %. Gravel larger than 6 mm diameter were omitted as a complicating factor and only soils containing less than 10 % thereof were sampled.

The most important routine soil analyses that were carried out on the samples included: maximum Proctor compaction and critical water content, particle density, modulus of rupture, aggregate stability, particle smoothness, organic carbon content, specific surface area, cation exchange capacity. Except for modulus of rupture (Richards, 1953) the analytical techniques described by Klute (1986) were used. The maximum density of each particle size fraction was determined by vibrating the material at a constant amplitude and time into accurately graded glass tubes with a 3.0 g mass resting on the fraction.

Stepwise multiple regression models were employed to predict compactibility as a function of particle size data as well as the statistics describing the distribution thereof after the publication by Moolman (1981).

The model of Gupta and Larson (1979) based on the random packing of soil particles of various sizes was employed to predict maximum, minimum and mean random bulk density for each sample.

RESULTS

Throughout the data analysis particle size distribution expressed as percentage of the total soil mass smaller than 6 mm yielded better predictions of soil compactibility than when the data was expressed on a smaller than 2 mm basis (data not shown). Therefore, only results based on a 6 mm basis will be reported in this paper.

The relationship between particle size distribution statistics and compactibility was best described by the equation,

$$\rho_b = -0.0792\ MP - 0.0350\ K + 2.343 \qquad R^2 = 0.571$$

where ρ_b is maximum Proctor bulk density (g/cm^3), MP is mean particle size on the Φ-scale, K is the moment coefficient of kurtosis (a measure of peakedness of the particle size distribution curve). Stepwise inclusion of the mass percentage of each particle size class by means of a multiple regression model (linear least squares) increased R-squared only to 0.615. The latter model fitting results are given in Table I.

Table I Model fitting results for the prediction of maximum Proctor density with particle size distribution data (< 6 mm diameter basis) as independent variables

Independent Variable	Coefficient	Standard Error of Estimate	T-value
Constant	2.291	0.059	38.71
Coarse sand	0.0015	0.00096	1.58
Very fine sand	-0.0027	0.0012	-2.28
Clay	-0.0065	0.0019	-3.40
Mean particle size (Φ scale)	-0.0317	0.0161	-1.97
Kurtosis	-0.0406	0.0052	-7.73

$R^2 = 0.615$ Durbin-Watson summary statistic = 1.737
Standard Error of Estimate = 0.0599

A plot of the such predicted and laboratory determined bulk densities is presented in Fig. 2. Although a wide variability around the 1 : 1 line is noticed these data again points to the relationship between soil texture and compactibility even over a wide range of soils from different origins. Closer inspection of the data with the aid of component effects plots (data not shown) clearly revealed that both increasing coefficients of kurtosis and clay contents resulted in lower maximum bulk densities.

With the packing model the best correlation (R^2) betweem maximum Proctor density and maximum predicted density was obtained when the soil particles were packed according to a dense tetragonal arrangement (Fig. 3). A slope of 1.0 is desired, but as the slope of 0.16 in Fig. 3 indicates maximum Proctor bulk density was totally overpredicted by this packing arrangement.

Average random bulk densities predicted by the model, and corrected for organic matter content, is compared graphically in Fig. 4 to the field measured bulk densities of the sample population. A much closer fit to the 1:1 line is noticed and the R^2-value is 0.35. Definite outliers are noticed on Fig. 4.

DISCUSSION

Multiple regression models employing textural data could account for a substantial proportion of the variation in maximum bulk density. However, auto-correlation (Durbin-Watson summary statistic = 1.737) between the independent variables places doubt on the possibilities to extrapolate beyond the limits of a specific data set.

It should be kept in mind that in this study maximum Proctor density was determined on the total soil mass that passes through a 6 mm sieve. The aggregates so included might be the reason why the soils could not be compacted to the high bulk densities predicted with the Gupta-Larson model (Fig. 3). This packing model uses clay-size particles to fill pores while clay in the field has a definite aggregating effect which is not accounted for by the model.

The prediction of the field bulk density, measured at the time of sampling, was much more successful (Fig. 4) despite the outliers. Soils that were recently cultivated were overpredicted by the average random bulk density and is indicative that these soils might in time recompact to the predicted values. The very sandy soils (ca. 90 % total sand fraction), which in addition contained more than 25 % coarse sand, were underpredicted when corrected according to Adams (1973) for the bulking effect of organic matter. Without such a correction these soils all fitted neatly onto the 1:1 line.

The field measured bulk densities of horisons containing illuvial clay (> 30 % clay) were underpredicted by the random packing, possibly because clay-size particles were washed into the pores. However, they were still overpredicted by the tetragonal packing. Undisturbed, well-drained, but naturally compacted, red and yellow subsoil horisons were underpredicted by random packing, but were well-predicted by tetragonal packing. From experience in the field these soils are known to have stable structure but they recompact to very high densities under wheel traffic once they have been loosened.

CONCLUSIONS

1) These results confirmed that soil textural data can be employed to predict compactibility for field situations, but with certain reserves.

2) As the outliers proved, no generally adequate prediction can be made on a textural basis alone. Therefore, in a follow-up paper the effect of other soil properties will also be quantified.

3) The ability of the random packing facility of the packing model to sort outliers into logic groups is a benefit in itself because it can add to identify soil management classes.

4) Another important outcome of this study is that the 2 - 6 mm particle size class should be included for compactibility studies.

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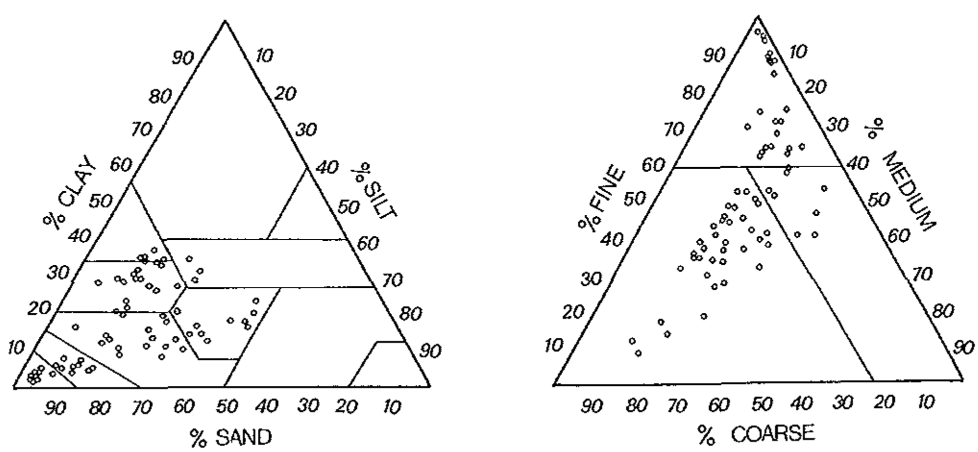

Fig. 1. Particle size distribution of the smaller than 2 mm fraction of the sample population, represented on a texture chart (left) and a sand-grade chart (right).

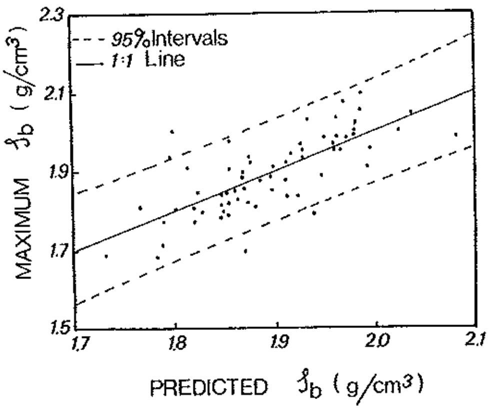

Fig. 2. Comparison of maximum Proctor bulk densities with bulk densities predicted by a multiple regression model based on particle size distribution data.

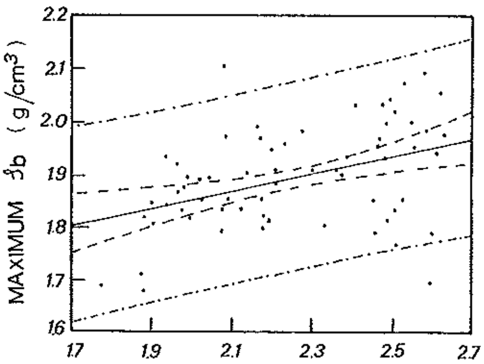

Fig. 3. Comparison of maximum Proctor bulk densities with bulk densities predicted by a packing model according to a tetragonal packing of soil particles.

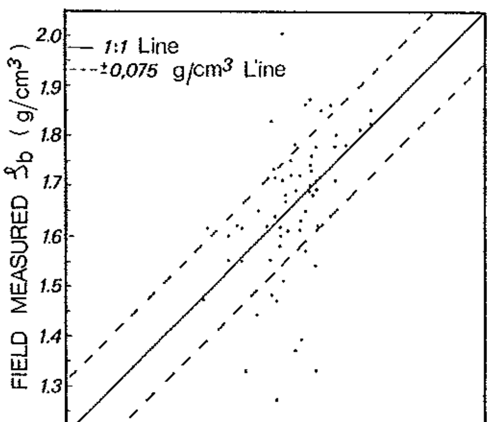

Fig. 4. Comparison of field bulk densities with bulk densities predicted by a packing model according to a random arrangement of soil particles.

USE OF SOIL-STRUCTURE TYPE DATA IN A SOIL-WATER MODEL TO ASSESS THE EFFECTS OF TRAFFIC AND TILLAGE ON MOISTURE DEFICIT, AERATION, AND WORKABILITY OF SANDY LOAM AND CLAY LOAM SOILS

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ABSTRACT

Different tillage and traffic practices have resulted in different soil-structure types, which could be recognized in the field. Physical properties of these distinct soil-structure types were measured and used as input for a soil-water model. Application of this model allowed evaluation of the effects of the tillage and traffic practices on moisture deficit, workability, and aeration for the actual soil-structure conditions and for the hypothetical situation that the soil structure was regenerated to a type that only occurs under old grassland. Daily weather data of thirty years were used for the simulation. Changes in soil-pore geometry are implicitly taken into consideration. Therefore, this approach may be more reliable for the prediction of crop response than existing machine-soil models.

INTRODUCTION

Crop response to tillage and traffic shows considerable variation between years and sites. Conducting field experiments to cover all variations is very time-consuming and expensive. Models simulating the machine-soil-crop system seem to be attractive alternatives. The entire system, however, has a very complex nature and is therefore often divided into subsystems, such as the machine-soil subsystem and the soil-crop subsystem. If soil compaction is dealt with, models describing the machine-soil subsystem can be used to predict iso-bulk-density lines in field soils resulting from an applied load at the surface (e.g. Gupta and Allmaras, 1987). However, bulk density alone is insufficient to describe all the changes in the pore system and related relevant soil-physical properties for the soil-crop models. Because knowledge is not available for predicting these changes, an alternative for modelling the machine-soil subsystem is adopted. Soil-physical properties are not simulated but selectively measured for different soil-structure types associated with various conventional tillage and traffic activities. Within one texture class these soil-structure types, which have mostly been developed in about the upper 50 cm of the soil, can be reproducibly recognized by soil surveyors in the field, as has been described by Kooistra et al. (1984; 1985). The soil-structure types are identified by measuring rooting patterns and soil-physical properties. These data, together with weather and water-table information, are needed as input for a soil-water model that is used to evaluate the effects of different soil-structure types on land qualities, such as moisture deficit, aeration, and workability.

The land qualities are expressed in terms of probability distributions, taking into account variation in weather conditions. The effects are currently being predicted for soils with a sandy loam, a loam, and a clay loam texture (Van Lanen et al., 1987). In the Netherlands these soils cover about 200,000 ha, which is 25% of the arable land.

The aims of this paper are illustrating modelling in which soil structure and soil water are key variables, and presenting some results for the sandy loam and clay loam soils.

METHODS AND MATERIALS

Soils, soil-structure types and physical properties

The sandy loam and clay loam soils considered have been developed in calcareous, young marine deposits and are classified as Typic Fluvaquents (Kooistra et al., 1985). Some relevant analytical data are presented in Table I. In

Table I. Analytical data of sandy loam and clay loam soils (Typic Fluvaquents) in use as arable land.

Horizon	Sandy loam				Clay loam			
	depth (cm)	clay content*	pH (KCl)	organic-matter content*	depth (cm)	clay content*	pH (KCl)	organic-matter content*
Ap	5-25	0.17	7.3	0.032	0-30	0.31	7.5	0.024
Cg1	45-60	0.13	7.5	0.008	30-55	0.34	7.4	0.021
Cg2	85-100	0.08	7.9	0.006	75-95	0.18	7.9	0.015

* as mass fractions

the Netherlands these soils are mainly used for arable farming and ploughpans are common. Attempts have been made to break these ploughpans up. In *old arable land* these cultivations have resulted in clearly different soil-structure types, including conventionally tilled soils with a primary ploughpan below the arable layer, and soils deeply loosened by rota-digging with or without a newly formed secondary ploughpan. Also *young arable land* (more than 5 and less than 10 years arable land after having been used as grassland) occurs with a primary ploughpan or a loosened-ploughpan soil-structure type. Futhermore, in small areas a soil-structure type with more favourable properties can be found in old grassland. For each different soil layer undisturbed samples were taken to measure hydraulic conductivity $k(h)$ and moisture retention $\theta(h)$ both as a function of pressure head h, as described by Kooistra et al. (1984; 1985).

In clay loam soils, free water moves vertically through macropores along an unsaturated soil matrix (bypass flow). For clay loam soils having an old-grassland or secondary-ploughpan soil-structure type, bypass flow as a function of soil moisture content was measured in undisturbed soil columns (height and diameter 20 cm) under a rainfall simulator. Depth of infiltration of bypass flow into the soil matrix of the subsoil ('internal catchment') was measured in field experiments as described by Van Stiphout et al. (1987).

Simulation model

The transient one-dimensional finite-difference simulation model ONZAT (Van Drecht, 1983) was used to calculate soil water regimes for a period of thirty years. It computes pressure heads, moisture contents, and air-filled porosities as functions of depth and time. Actual evapotranspiration is also simulated. A subroutine simulating bypass flow in clay loam soils was built into the model (Van Stiphout et al., 1987). The upper-boundary condition is defined by daily rainfall and potential evapotranspiration, the lower-boundary condition by water-tables. Input data, specially measured for this study, comprise $k(h)$ and $\theta(h)$ relations, root distribution, and bypass flow data.

Land qualities

Moisture deficit is defined as the difference between potential and actual evapotranspiration accumulated over the growing season. The moisture deficit is computed on a daily basis. *Workability* is evaluated according to a procedure proposed by Van Wijk and Feddes (1986). Simulated daily pressure heads in the topsoil are compared with a critical pressure head (threshold value) below which soil conditions allow field operations. The threshold value depends on soil characteristics (e.g. texture, organic-matter content, $CaCO_3$ content) and crop. Air-filled porosity is used as a global indicator for *aeration*. Aeration is assumed to be satisfactory when air-filled porosity is above a threshold value of 0.1 (e.g. Gupta and Allmaras, 1987). Probabilities of occurrence of a soil moisture deficit, a workable day, and adequate aeration are calculated from simulated moisture deficits, pressure heads, and air-filled porosities on a daily basis, using a historical record of thirty years' weather data. Simulation has to be repeated for all the different soil-structure types occurring in each soil type.

RESULTS

Measured physical properties of soil-structure types

Soil water retention characteristics (mean value and range) at different depths are presented in Figure 1A for soil-structure types found in old grassland and young arable land on *clay loam soils*. Hydraulic conductivities

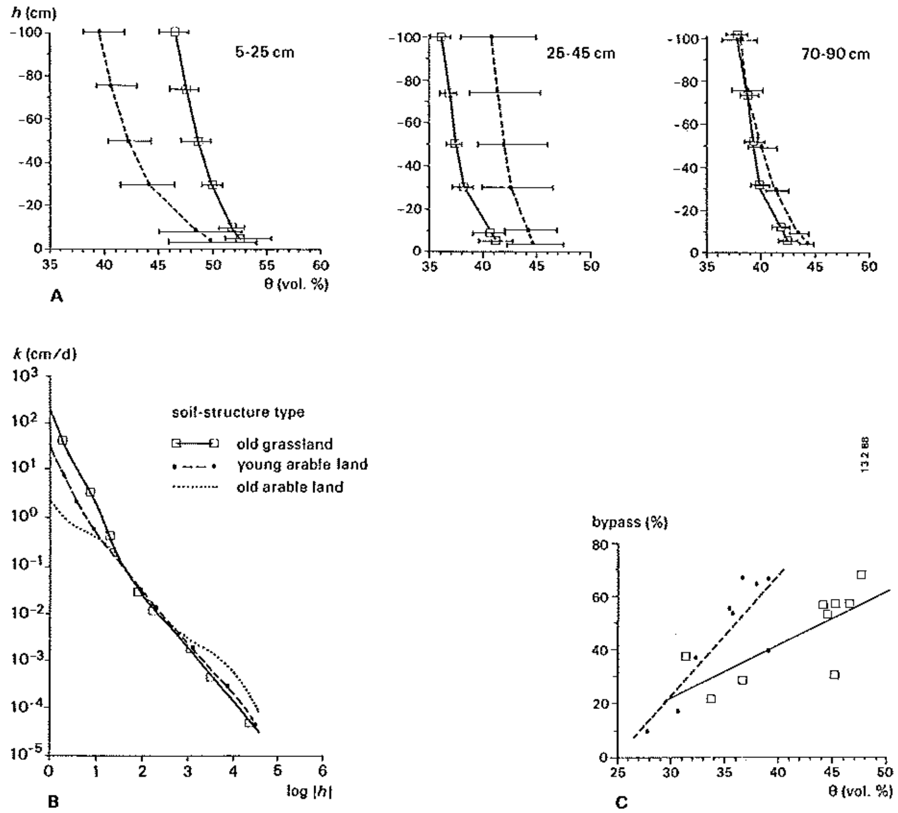

Fig. 1 Moisture retention (A), hydraulic conductivity (B), and bypass flow (C) for different soil-structure types in clay loam soils

for the soil just below the ploughlayer are given in Figure 1B for different soil-structure types. Similar to sandy loam soils (Kooistra et al., 1984; 1985), in clay loam soils tillage and traffic practices are also clearly reflected in the physical properties of the upper 50 cm of the soil. Although the texture of these soils is nearly the same, physical properties of the soil-structure types are significantly different for the layer at a depth of 30-45 cm. Moreover, the properties of the grassland topsoil (5-25 cm) differ from those of the ploughlayer of young arable land. The subsoils show hardly any differences. Differences in bypass flow (expressed in % of applied rain) between clay loam grassland and arable land topsoils are shown in Figure 1C.

Simulated land qualities

Probabilities of occurrence of a workable day, a soil moisture deficit, and adequate aeration are presented in Figure 2 for different soil-structure types in *sandy loam soils* (see also Van Lanen et al., 1987). Workability and aeration for soils with a loosened or a secondary ploughpan (excluded from Figs. 2A and 2C) hardly differ from those for soils with a primary ploughpan. Under Dutch conditions, effects of subsoiling may only be expected, if field traffic practices are radically changed. In exploratory simulation runs, potatoes were assumed to grow in old-grassland soil structure without deteriorating it. This assumption is made to explore what can maximally be attained by soil-structure regeneration. Figure 2B shows that under Dutch conditions potatoes grown on sandy loam soils never suffer severely by drought, irrespective of soil-structure type. However, in dry years, soils with arable-land soil structures are more susceptible than soils with a structure comparable to old grassland. In dry years, soil-structure regeneration in sandy loam soils can maximally decrease soil moisture deficits by about 50%. The more favourable soil structure of old grassland is also expressed in the land qualities workability and aeration (Figs. 2A and 2C). Soil-structure improvement in sandy loam soils may result in an increase in workable days and days with adequate aeration during relevant periods up to 20 and 10% respectively.

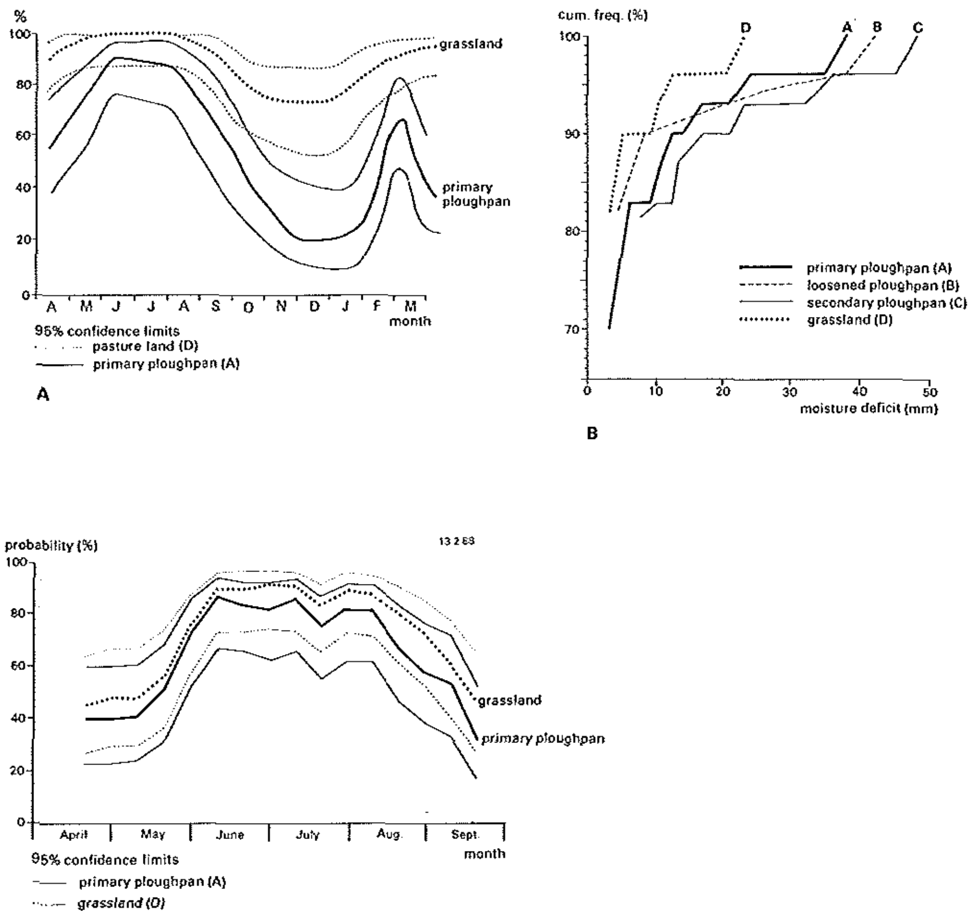

Fig. 2 Probabilities of occurrence of a workable day (A), a moisture deficit (B), and adequate aeration (C) for different soil-structure types in sandy loam soils

CONCLUSIONS AND DISCUSSION

(1) Changes in soil-physical conditions resulting from different tillage and traffic practices can be quantified by measuring physical properties of tillage- and traffic-associated soil-structure types and using them in soil-water simulation models.

(2) By this approach effects of actual and hypothetical soil-structure conditions can be evaluated with regard to the scope for soil-structure regeneration or the feasibility of loosening plough-pans.

(3) As long as currently available machine-soil models are not able to simulate the physical properties, which also reflect changes in soil-pore geometry (e.g. continuity, mutual connection), this approach may be reliable to predict effects of machinery on crops. However, further development of machine-soil models should be encouraged, because the proposed approach cannot cope with effects of presently non-existing tillage and traffic practices. Measured physical properties of the different soil-structure types could probably be used in the validation process of the machine-soil models.

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PREDICTION OF WORKABILITY AND EMERGENCE DATE IN DEPENDENCE ON SOIL AND DRAINAGE CONDITIONS

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ABSTRACT

Timeliness of field operations in spring is primarily governed by the moisture conditions in the top soil. These vary continuously and depend on rainfall, evaporation, soil physical properties and drainage conditions. A model approach is presented to evaluate the effect of soil and drainage on workability, sowing/planting and emergence time. Essential in the approach is a numerical model that simulates the soil moisture regime on a daily basis from weather, soil and drainage input data. Soil water pressure head limits are defined as the critical pressure heads at which field operations are still possible without spoiling soil structure. These limits are used to derive duration and frequency of an adequate workability. After sowing/planting the duration of germination is predicted from a relationship between the heat sum required for emergence and the moisture conditions in the seedbed. This is performed with mean daily air temperature and simulated pressure heads in the seedbed.

INTRODUCTION

With increased farm mechanization and intensified land use soil utilization conditions, such as workability in spring are of increased importance for farm output. The earlier the sowing, the longer the growing period and in general the greater the crop yield. In spring farmers encounter short term variations in workability. These are primarely governed by changes in soil moisture conditions that in term depend on weather, soil and drainage conditions. Field research on the effects of these factors on the timeliness of field operations and early growth in spring is prohibitively costly, because reliable results can only be obtained after many years of experimentation. This paper presents a simulation technique developed to quantify time and distribution of workable days and crop emergence in dependence on weather, soil and drainage conditions. The model approach is presented in Fig. 1.

SIMULATION SOIL MOISTURE CONDITIONS

Workability may change from day to day depending on soil moisture conditions. Consequently, the model must compute a detailed soil water balance, at least on a daily basis. In the approach presented, the numerical model FLOWEX is applied (Buitendijk 1984, Van Wijk 1987). FLOWEX computes the terms of the water balance of a non-cropped soil profile, that may consist of different layers. The model is based on an integrated form of the Darcy flow equation assuming an exponential relationship between hydraulic conductivity and soil water pressure head. Combination with the continuity equation results in a description of the non-steady state flow

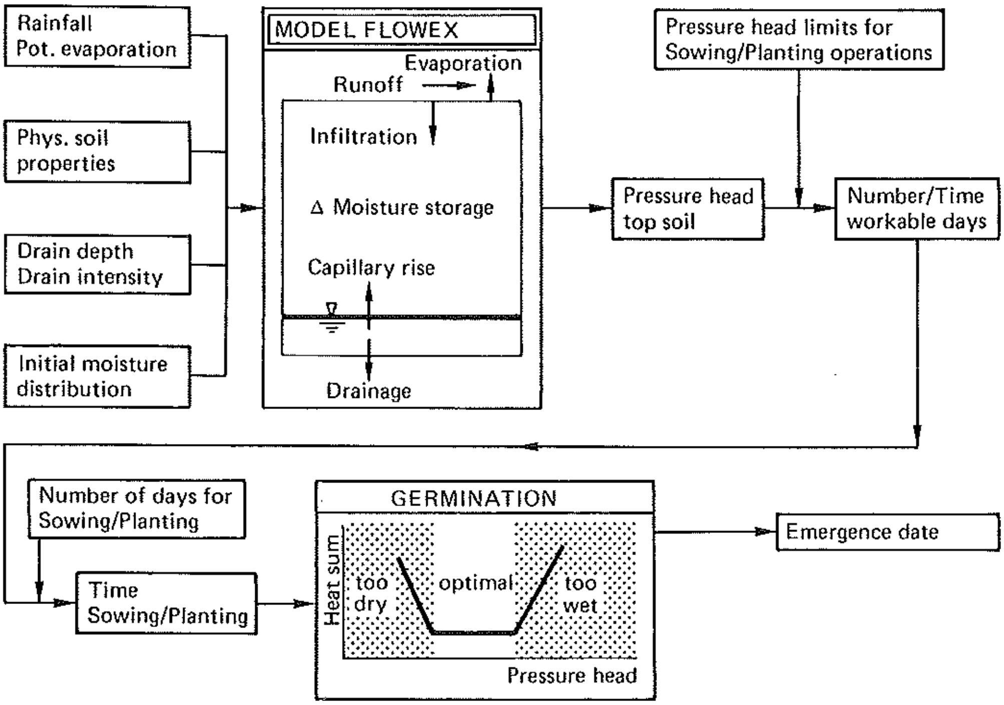

Fig. 1. Flow chart for computing the influence of drainage and soil on workability and emergence date

process, layer by layer for consecutive time increments. Rainfall/potential soil evaporation are boundary conditions at the soil surface. As boundary condition at the bottom a flux -groundwater table depth relationship, based on the HOOGHOUDT-ERNST drainage theories is applied.

Input to FLOWEX is: rainfall and potential soil evaporation on a 24-hour basis, soil water retention and hydraulic conductivity curves for the different soil layers, drain depth and drain intensity and finaly the initial soil water profile. Output of the model includes all terms of the water balance, the distribution of soil water content, pressure head and fluxes with depth. The suitability of the soil for field operations depends on the pressure head in the top layer of the soil. For this purpose the pressure head computed at 5 cm depth is taken.

MODELING WORKABILITY

Soil moisture limits that are critical for workability were obtained from field research. In spring and autumn of two rather different meteorological years measurements of the soil water pressure head were carried out at depths of 5, 10, 15, 20 and 30 cm in a number of different soils. Simultaneously farmers were asked to give a daily "best professional judgement" (good, moderate and poor) of the suitability of the soil for field operations. They were allowed to give an appraisal of good only then, when they were sure that no subsoil compaction and structure deterioration of the tilled layer would occur. Confrontation of the farmers' appraisal with in situ measured pressure heads showed that the farmers' judgements of soil suitability for field operations in spring were best correlated with pressure heads at 5 cm. A summary is presented in Table 1.

MODELING SOWING/PLANTING DATES

Good workability refers not only to soil conditions but also to a time in spring as close as possible to the optimum sowing/planting date. For the conditions prevailing in the Netherlands these dates are for spring cereals 1 March, for sugar beet and potatoes 20 March. At the present level of mechanization the farmers in the Netherlands use on an average one day for sowing spring cereals, two days for sowing sugar beet and 4 days for planting potatoes. Knowing the optimal sowing/planting dates and the number of days required for these operations, time and number of workable days and sowing/planting time can be derived from the simulated pressure head at 5 cm depth with the aid of the workability limits from Table 1.

MODELING GERMINATION AND EMERGENCE

Length of germination period will vary from year to year, depending on temperature and soil moisture conditions in the seedbed. The earlier the sowing date, the longer germination will take, in general. From sowing-emergence experiments in the field relationships could be derived between the heat sum required for a certain percentage of emergence and the soil water pressure head in the seedbed (Van Wijk and Feddes 1986). Fig. 2 depicts such relationship for potatoes. Simular relationships are available for spring cereals and sugar beet. For the emergence of a number of crops a constant heat sum was found when the pressure head ranges between -100 and -500 cm. Outside this range germination was retarded through either abundancy or shortage of soil water. Starting at the sowing date a heat sum is now calculated day by day according to the relationship given in Fig. 2 with the mean 24-hour air temperature and the simulated pressure head at 5 cm depth in the seedbed.

Table 1. Soil water pressure heads at 5 cm depth at which field operations for sowing of spring cereals and sugar beet and planting of potatoes are still possible without detrimental effects on soil structure.

	Soil water pressure head (cm)		
	Spring cereals	Sugar beet	Potatoes
Sandy soils	-50	- 70	- 70
Silt/sandy loam (8-20% particles <2 μm)	-80	-100	-100
Loam/silty clay loam (20-40% part.<2 μm)	-60	-100	-120
Silty clay (>40% particles <2 μm)	-40	- 60	- 80

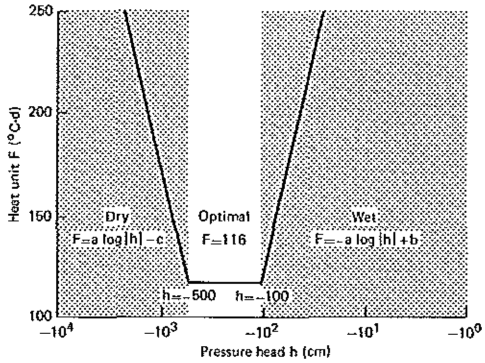

Fig. 2. Relationships between the heat sum required for emergence of potatoes, based on mean daily temperatures and the soil water pressure head in the seedbed (after Van Wijk and Feddes, 1986).

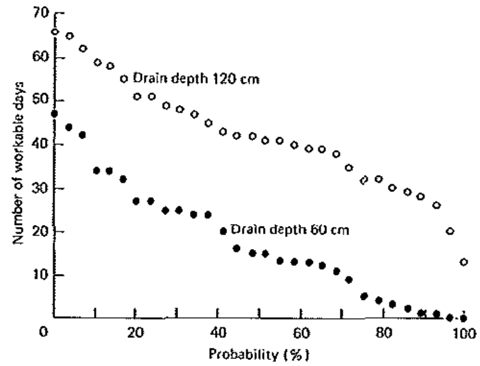

Fig. 3. Model computation of the probability that a number of workable days for potato planting is exceeded in the period 20 March to 31 May. A workable day is defined as a day with a soil water pressure head at 5 cm depth not exceeding -100 cm (cf. table 1). The relationships refer to a sandy loam soil drained at depths of 60 and 120 cm. Each point represents one year out of the period 1952-1981

EFFECT OF SOIL AND DRAINAGE ON WORKABILITY AND EMERGENCE DATE

Fig. 3 represents results of a model computation of the number of workable days for potato planting over a 30-year period. At the 60 cm drain depth there are years without workable days before the end of May. Increasing drain depth from 60 to 120 cm increases the number of workable days considerably. In very wet years there is a probability of 100% that 12 or more workable days occur in the period between 20 March and 31 May. Knowing the planting date the model calculates the duration of germination and emergence date on basis of the mean daily air temperature and the simulated pressure head in the seedbed, in the way described before.

Fig. 4 shows the emergence date of potatoes grown on the sandy loam soil for each separate year at three different drain depths with comparable drain intensities. It appears to be very effective to increase drain depth. Going from a drain depth of 60 to 90 to 120 to 150 to 180 (all in cm) the 30-year averaged emergence date advances with 10, 21, 24 and 25 days respectively. This shows that the advancement of emergence dates becomes less progressive with further increasing drain depths. Increase of drain depth goes in general together with deeper groundwater tables, hence with less potential for capillary rise from the groundwater and thus a more rapid drying of the top soil.

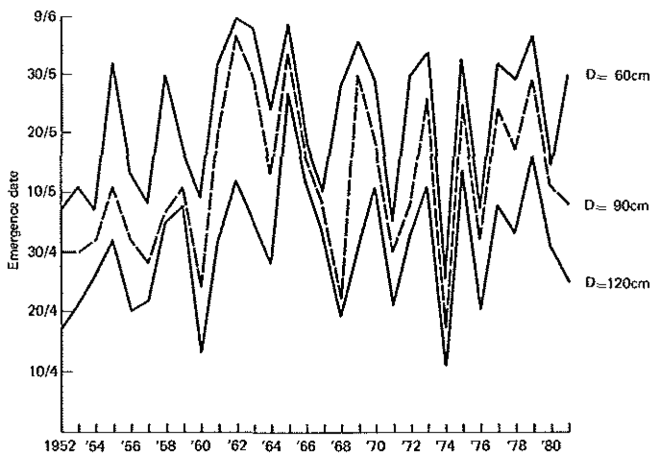

Fig. 4. Yearly emergence dates of potatoes on a sandy loam simulated over a 30-year period at three different drain depths

Fig. 5 shows that for sandy loam both drain depth and intensity (distance) greatly influence the earliness of ermergence whereas for loam on sand this is less pronounced. This difference in behaviour can be ascribed to the difference in hydraulic conductivity of the sandy loam soil and the 40 cm loam cover. The lower the hydraulic conductivity of a soil, the lower the capillary rise from the groundwater table, the less the soil water conditions at the top are influenced by the groundwater table depth. In other words: the evaporation rate from the top soil cannot be met by the water supply from below. The heavier the soil, the more pronounced this behaviour. Combining this model with models that simulate crop water use and dry matter production enables to quantify the timeliness *penalty* due to differences in workability and emergence date in terms of yield.

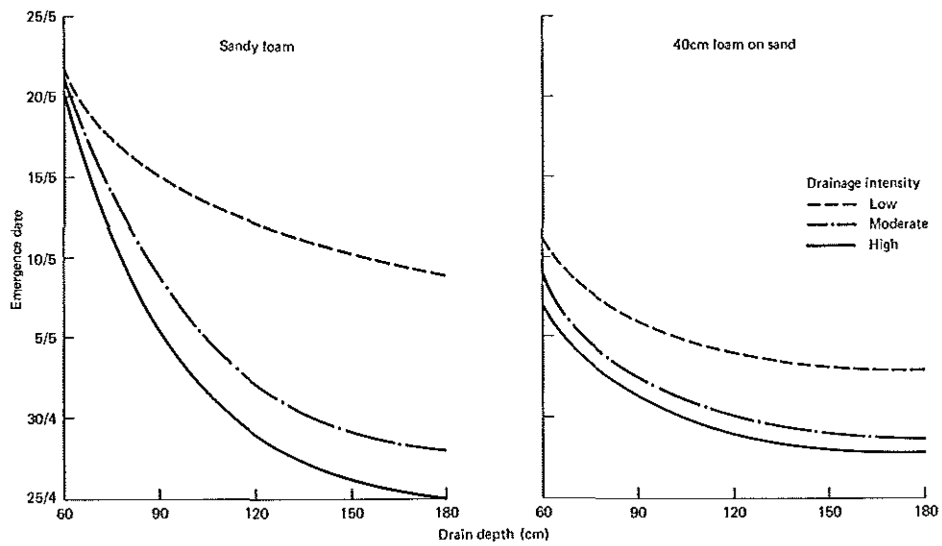

Fig. 5. Influence of drain depth and intensity on the emergence date of potatoes growing on a sandy loam and a 40 cm loam on sand soil, based on a simulation over the period 1952-1981.

Van Wijk and Feddes (1986) give an example of such an integrated model that can be used to evaluate effects of soil and land drainage on farm management and crop yield.

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MODELISATION OF STRESS-DISPLACEMENT INTERACTION BETWEEN ROOT ANALOGUE AND SOIL.

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ABSTRACT.

A non-linear finite element model for stress-displacement interaction between root and soil is presented. Using the laboratory stress-strain uniaxial compression curves at different soil moistures, the model is tested for radial expansion and axial penetration in loam. The comparison of computed values with results of in situ penetrometer and pressiometer measurements made at different water contents shows good concordance.

INTRODUCTION.

Root growth, radial expansion as axial elongation, is affected by soil mechanical properties. Although quantitative information regarding this matter is essential for a good understanding of phenomena involved, only little is reported about laboratory experiments and nothing about in situ measurements. This is due to the difficulty of accurately measuring stresses, strains, forces and displacements in field conditions.

Some authors (Leclercq et al.1984, Collis-George et al. 1985, Misra et al. 1986) have set up an analytical model describing stress and displacement interaction between soil and root during radial or axial growth. There is however a limit of validity for such equations, for they consider soil as a continuum submitted to average stresses and strains as opposed to the discrete forces and displacements met by root between macroscopically structured soil. Such a theory has yet to be developed and some experiments (Greacen et al. 1969,Whiteley et al. 1981) indicate that for dimensions larger than 1 mm the strength of material formulation may be used. The corresponding analytical equations are usually implicit and must be solved iteratively or with the aid of tables. Moreover, non-linear behaviour of soil is hardly taken into account.

So, a numerical non-linear finite element model was set up. Because of the difficulty measuring in situ soil-root stress or strain interaction, the validity of the model has first been tested on simulations of field measurable experiments: penetrometer and pressiometer tests at various soil moistures. The former corresponds to the root axial elongation and the latter to the radial expansion. These first results are presented here.

SOIL TESTS.

The soil investigated is a typical loam of the Gembloux area, having following physical properties:

Sand: 5 to 10%
Silt: 65 to 75%
Clay: 20 to 25%

Liquid limit: 35%
Plastic limit: 21.5%
Plasticity index: 13.5%

Sampling for laboratory tests occurred at the end of April on a soil tilled in autumn. Disturbed and undisturbed samples were taken between 7 and 15 cm depth just before beet sowing. At the same time a first set of 10 penetration tests was performed from soil surface up to 53 cm depth with a Findlay Bush Recording Penetrometer using a standard cone, 0.5 inch diameter. Those measurements occurred every 3.5 cm. Moisture and density measurements were also made on soil slices 5 cm thick, sampled in the proximity of the penetration tests.

These 3 kinds of tests were repeated at intervals varying from 2 to 4 weeks until mid-July, giving various moisture-penetration resistance profiles.

In September, we had the opportunity of performing also two in situ pressuremeters tests with an Arpageo device having a one cell probe 30 cm long and 2.4 cm O.D. Measurements occurred every 30 cm from 10 to 200 cm depth. Soil moisture was also measured.

The mean results of 9 laboratory triaxial tests on undisturbed saturated samples are:

	Total stresses	Effective stresses
Cohesion (kPa)	30.8	27
Internal friction angle (°)	31.9	35.2

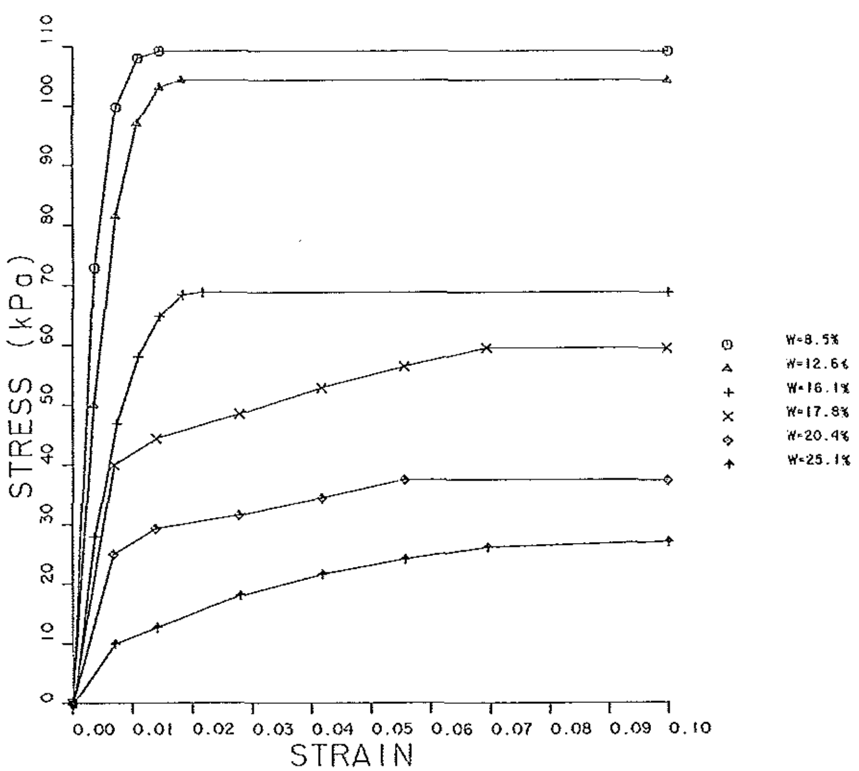

FIG. 1: SOIL COMPRESSION CURVES AT VARIOUS MOISTURE CONTENTS

Unconfined compression tests at various moisture contents between saturation (w=25.2%) and w=8.5% were also performed. Figure 1 shows the resulting stress-strain multilinear curves ready for use in the calculations.

THE FINITE ELEMENT MODEL.

The finite element model is a 364 nodes axisymmetric mesh with 2 materials, the root and the soil, separated by a friction contact surface. Figure 2 shows the meshes corresponding to the two materials.

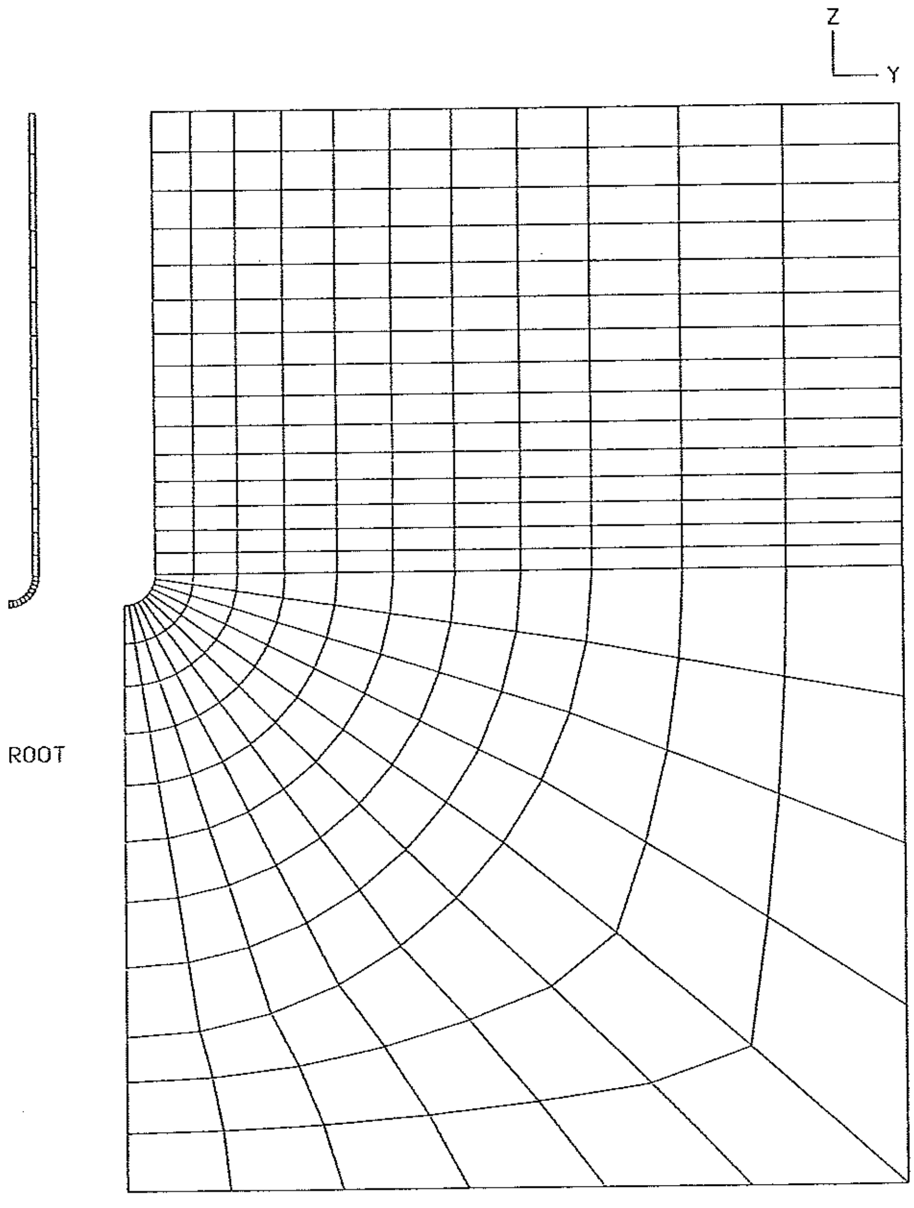

FIG.2: FINITE ELEMENT MESHES

For the root, only its outer part corresponding to a wall thickness of one fifth of the radius has been modelised for the tip and a cylindrical portion of 15 times the radius length. This was done using 52 nodes, forming 25 isoparametric 4 nodes elements. Inside that shaft a radial uniform pressure applied on the tip or/and on the cylindrical part was increased to produce axial or radial displacements.

The 312 remaining nodes modelise the 275 isoparametric 4 nodes soil elements. Boundaries are set at 25 times the root radius in radial direction and 20 times in the vertical direction under the tip. These values were chosen after some trials with different meshes and are in accordance with those reported by Whiteley et al. (1981) for test cores. The soil effects outside the boundaries are taken into account by the introduction of equivalent overburden soil pressures.

As the testing of the model in axial elongation was used to simulate the penetrometer, the root properties have been replaced by those of steel and the friction coefficient between tip and soil has been taken equal to 0.3. This value correponds to one half of soil internal friction angle.

Soil being a non-linear hysteretic material, a plastic multilinear model with isotropic hardening and a maximum of 7 linear segments has been chosen to represent the soil uniaxial stress-strain behaviour (fig. 1).

Calculations were performed with the SOLVIA (Solvia 1987) finite element codes using large displacements and strains formulations.

RESULTS.

Radial expansion.

As the pressuremeter was available only for one day, the two tests results correspond to a same in situ moisture profile. For the layer between 10 and 40 cm depth, the mean moisture was equal to w=17%, giving an experimental limit pressure pl=720 kPa. The numerical simulation of this test was performed using the curve of figure 1 corresponding to w=17.8%. The computed limit pressure for radial expansion was pl=700 kPa.

Axial penetration.

The mean values of the different in situ cone resistances measured respectively at 7, 10.5 and 14 cm depth are presented in figure 3 against corresponding soil moisture content. Penetration resistances were computed using the laboratory stress strain curves available for various moistures. Those results are also plotted on figure 3.

DISCUSSION.

For both radial and axial expansion the computed and experimental results agree fairly well. The finite element model is thus adequate to describe the phenomena involved, by soil mechanical devices like pressuremeters and pressiometers. As it is known, there is a relative difference between those tools and roots: the former are rigid while the latter can turn to follow planes of weakness or to make use of small-scale heterogeneities in soil properties. This is hardly possible to introduce in analytical models, while finite element models allow for the use of friction surfaces and the change in the properties of one or more elements in the mesh. However, before such a model can be tested, there is need for more experimental data about soil-root interaction measurements, and about distribution of local soil heterogeneities.

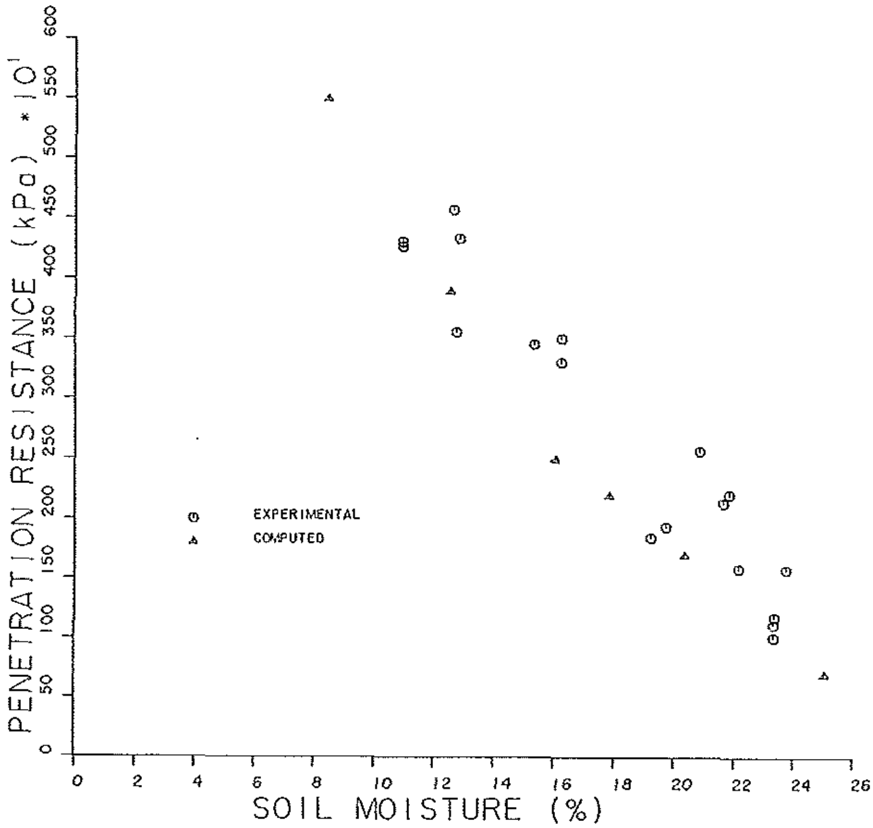

FIG.3 EXPERIMENTAL AND COMPUTED RESULTS FOR PENETRATION

ACKNOWLEGMENTS.

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SIMULATION OF SEEDBED SOIL MOISTURE AND TEMPERATURE BEHAVIOR AS EFFECTED BY TILLAGE OPERATIONS

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ABSTRACT

Soil moisture and temperature of the seed zone in dry land farming are mainly effected by the surface evaporation and the structure of the seedbed. A two-dimensional model of evaporation from the surface of flat heterogeneous soil or ridge and furrow was developed and a computer program for simulation of seedbed soil moisture and temperature behavior as effected by different tillage operatoins was compiled and validated by field experiment.

INTRODUCTION

S.C. Gupta (1984) developed a model using daily maximum and minimum atmospheric temperature to predict soil temperature under various tillage and residue conditions, but that model did not incorporate the coupled interaction with moisture. D.E. Holzhei and T.H. Burkhardt (1985) developed a two-dimensional soil physical model that can be applied to analyze the moisture and temperature regime in the seedbed zone using a finite element formulation, but it can not be applied to analyze the ridge and furrow tillage which is commonly practiced in Northwestern China where more than 50% of arable land is in arid and semi-arid region and the agricultural production of this area has to depend heavily on natural rainfall.

The objective of this study was to develop a two-dimensional model that could be used to analyze the seedbed soil moisture and temperature behavior as effected by different tillage operations such as leval sowing, compaction, minimum tillage, ridge and furrow tillage etc., with the purpose of predicting and optimizing tillage operations and tillage implements for these areas.

THEORY AND METHODS

One and Two Dimensional Models for Flat Field Surface

For predicting the soil moisture and temperature distribution, the evaporation rate Es and surface temperature Ts must be knomn. The Es and Ts can be calculated using one-dimensional evaporation model from bare soil surface (Van Bavel and Hillel, 1976; Camillo, 1986; Yang and Zeng, 1987) for one-dimensional situations such as level sowing, soil compaction etc. (Fig. 1).

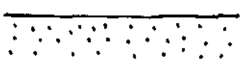

Fig. 1. One-dimensional tillage pattern

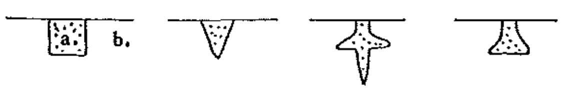

Fig. 2. Two-dimensional pattern with flat surface: a. tilled portion b. non-tilled portion

The one-dimensional model can also be applied to analyze two-dimensional evaporation from the soil surface of minimum-till pattern (Fig. 2). The bulk density of tilled and non-tilled soil are different in this case, and we can calculate the different evaporation rate from each surface element using finite element method by one dimensional evaporation model.

Evaporation Rate from the Surface of Ridge and Furrow

The undulation of ridge and furrow affects the radiation and wind speed. Considering the change in energy balance and aerodynamic resistance, a model was developed to predict the Es and Ts from the surface of ridge and furrow.

The furrow (Fig. 3) can be described mathematically as follow:

$$z = h + h \cdot \cos(\pi x/W) \tag{1}$$

where h=H/2, H is the height of the ridge; W is the width of the furrow; W' is the width of the ridge. The dot line in Fig. 3 is the idealized furrow.

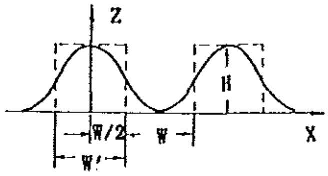

Fig. 3. Mathematical description of an furrow

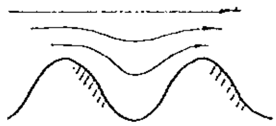

Fig. 4. Wind direction perpendicular to the furrow

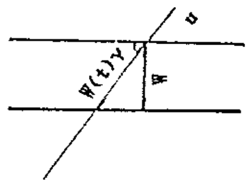

Fig. 5. Wind direction across the furrow

When the wind direction is perpendicular to the furrow (Fig. 4), the aerodynamic resistance at a point (x,z) on the suface is

$$Ra(x,z) = u_z/u_*^2(x,z) \tag{2}$$

where: u_z is the wind speed at a reference elevation; $u_*(x,z)$ is the friction velocity, and

$$u_*(x,z) = ku_5(x,z)/Ln(0.05/Zo) \tag{3}$$

where k is von Karman constant; $u_5(x,z)$ is the wind speed at the height 0.05 m above the surface of the furrow; Zo is the roughness. Using a data set of wind speed measured by hot wire anemometer in the field, the u_5 may be estimated by

$$u_5(x,z) = (a+b(d \cdot H/W)^c \cos(\pi x/W)) \cdot u_z \tag{4}$$

where a, b, c, d are the fitted paramiters.

If wind direction is parallel to the furrow,

$$Ra(x,z) = [Ln(Zc(x,z)/Zo)]^2/(k^2 u_z) \tag{5}$$

where Zc is the corrected reference elevation,

$$Zc = Z - h \cdot \cos(\pi x/W) \tag{6}$$

If the wind direction makes an angle γ with the furrow (Fig. 5), it can be treated as though the wind blows across a wider furrow. The transient width W(t) and the x coordinate X(t) are:

$$W(t) = W/\sin\gamma \tag{7}$$

$$X(t) = x/\sin\gamma \tag{8}$$

then, the Ra can be calculated just as in (2)-(4). If $\gamma < 15°$, we can take the wind as parallel to the furrow.

At time t, the Es(x,z,t) can be calculated on each surface element,

$$Es(x,z,t) = [Hs(x,z,t)-Ha(t)]/[Ro(x,z,t)+r_s(x,z,t)] \tag{9}$$

where Hs(x,z,t) is the absolute humidity of air (kg/m^3) at surface point (x,z), Ha is the air humidity (kg/m^3), and

$$Hs(x,z,t) = Ho \cdot \exp[\psi g/R(Ts+273.16)] \tag{10}$$

where Ho is the saturation humidity (kg/m^3) at the surface temperature Ts(x,z,t), ψ is the matric potential of the moisture in the 0 to 1 cm surface layer, g is acceleration of gravity, R is the gas constant.

$r_s(x,z,t)$ is the soil surface resistance (Camillo, 1986),

$$r_s(x,z,t) = a+b\ (\theta s-\theta) \tag{11}$$

where θs is the saturation soil moisture, θ is the soil moisture content, a and b are the fitted paramiters.

$$Ro(x,z,t) = Ra(x,z,t) \cdot St \qquad (12)$$

where Ra(x,z,t) can be calculated by (2) - (8), St is the stability correction paramiter (Van Bavel and Hillel, 1976).

Surface Temperature on the Ridge and Furrow

The ridge will affect the radiation balance of the soil surface. Considering the different values of H, W, azimuth β of the furrow, the latitude of the site, the changing sun height angle h_o, and azimuth of the sun A, we can determine the shading and no shading area on the surface of the furrow. In no shading area, the globle radiation Rg at the point (x,z) at time t is

$$Rg(x,z,t) = S\alpha\beta + Rd \qquad (13)$$

where Rd is the diffuse radiation, $S\alpha\beta$ is the direct radiation at that point,

$$S\alpha\beta = Sm[\sin(h_o)\cos\alpha + \cos(h_o)\sin\alpha\cos(A-\beta)] \qquad (14)$$

where α is the slope at the point, Sm is the direct radiation from the sun. In shading area ,

$$Rg = Rd \qquad (15)$$

When the surface is divided into several elements and the Rg is different on each element, then, the Ts(x,z,t) of each element can be calculated as one-dimensional situation.

Trasport of Moiture and Heat in Soil

Based on the theory of simultaneous transfer of heat and moisture in porous media (Philip and de Vries, 1957), the governing equtions are

$$Cw(\partial\psi/\partial t) = \nabla\cdot(Kw\nabla\psi)+\nabla\cdot(Dv\nabla T)-\partial K/\partial z \qquad (16)$$

$$Ch(\partial T/\partial t) = \nabla\cdot(\lambda\nabla T)+\rho_L L\nabla\cdot(Kv\nabla\psi) \qquad (17)$$

where Cw is specific moisture capacity, Dv is the thermal vapor diffusivity, K is hydraulic coductivity. Kw is defined as follows

$$Kw = K+Kv \qquad (18)$$

where Kv is vapor conductivity due to potential gradients, Ch is the volumetric heat capacity, λ is the soil thermal conductivity, ρ_L is the the density of liquid water, and L is the latent heat of vaporization.

The boundary conditions along soil-air interfaces are

$$-Kw(\partial\psi/\partial n)-Dv(\partial T/\partial n)+\partial K/\partial z = Es(x,z,t) \qquad (19)$$

$$-\lambda(\partial T/\partial n)-\rho_L L\, Kv(\partial\psi/\partial n) = S(x,z,t) \qquad (20)$$

where n is the outer normal vector on the boundary, Es(x,z,t) is the evaporation rate, and S(x,z,t) is the soil heat flux which can be estimated by the energy balance equation:

$$S(x,z,t) = Rn(Ts)-LEs(Ts)-H(Ts) \qquad (21)$$

where the net radiation Rn, the latent heat flux LEs, and the sensible heat flux H are functions of Ts(x,z,t), and the calculations refer to Van Bavel and Hillel (1976), Yang and Zeng (1987).

Computer Program

The computer program was written in FORTRAN 77, The input data include soil physical parameters, meterological data, tillage operation pattern and the finite element domain and grid. Fig. 6 shows the finite element idealization for milimum-till, and Fig. 7 is for furrow and ridge tillage. The sequence of calculation was as follows: at each new time step, the Es and Ts were esminated and with the Eqs. (19)-(20) as the boundary conditions, the non-linear and coupled equations (16) and (17) were solved by Galerkin-type finite element aproach, then iterated until the temperature and moisture content both converged within a suitable tolerance.

Validation of the Model

For the validation of the model field experiments were performed in the Yucheng Experiment Station of the Chines Academy of Sciences from April 26 to May 1, 1987. Meteorological data (the diffuse and direct solar radiation, wind speed and direction, air temperature and humidity) were measured in the field. Soil moisture content was measured using gravimetric method at depth 0-1, 5, 10, 20 cm and by a neutron soil-moiture meter at depth 30-100 cm. The surface temperature was measured with a infrared thermometer, and the temperature at depth 5, 15, 20, 40, 80, 120, 140 cm were measured by mercury thermometer.

Soil physical parameters such as hydraulic conductivity K, soil-moisture characteristic curve, were measured in the laborotory. The functions as described by de Vries (1975) were applied the for soil heat capacity Ch and the thermal conductivity λ estimation, but the coefficients were fited by measured data in the laborotory. The calculation of Kv and Dv refered to Philip and de Vries (1957).

The soil moisture and temperature distribution of the one-dimensional tillage, minimum-till, and ridge and furrow till pattern for a duration of 120 hours were measured and calculated, but only that for the ridge and furrow were shown here in Fig. 8-9. In general, there were good agreement between the field data and the results obtained by the numerical methods.

RESULTS AND DISCUSSION

Several minimum-till seedbed prepared by different combination of operations (Fig. 2) can be analyzed, but only the simulated moisture and temperature of the ridge and furrow tillage were listed here in Fig. 10-11 with the same soil and meterological data as used in the validation experiment of the model.

Fig. 10 is the simulated temperature and moisture content distribution as effected by different depth of furrows. The temperature is lower and moisture is higher when the furrow is higher. Fig. 11 is the simulated soil moisture and temperature distribution as effected by the different furrow azimuth with the help of the program. The optimum tillage practice can be defined according to the local soil and meterological data of a locality.

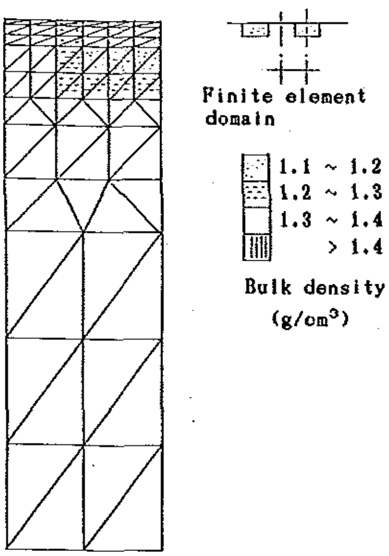

Fig. 6. The finite element grid for minimum-till pattern

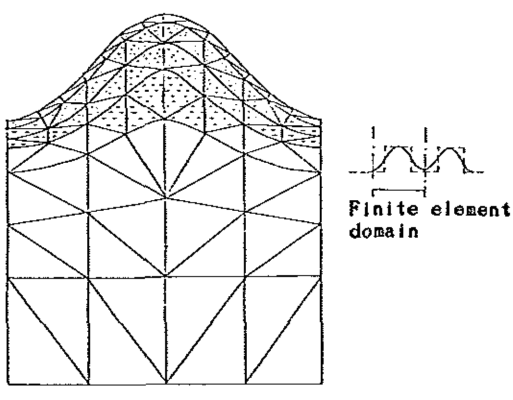

Fig. 7. Finite element grid for the ridge and furrow tillage pattern

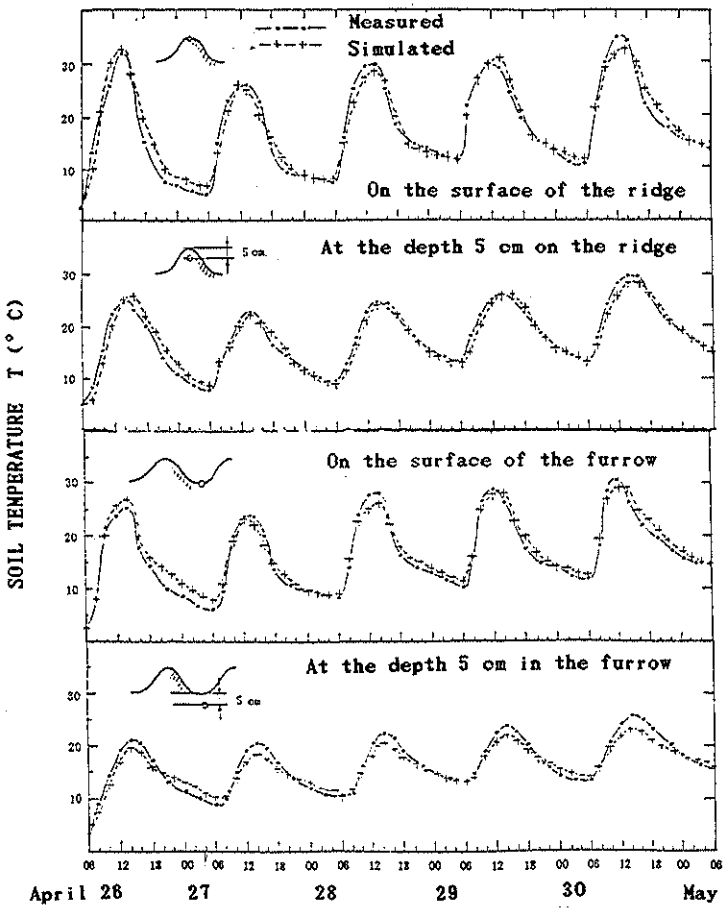

Fig. 8. The comparison of measured and calculated temperature at the depth of 0 and 5 cm in the ridge and furrow

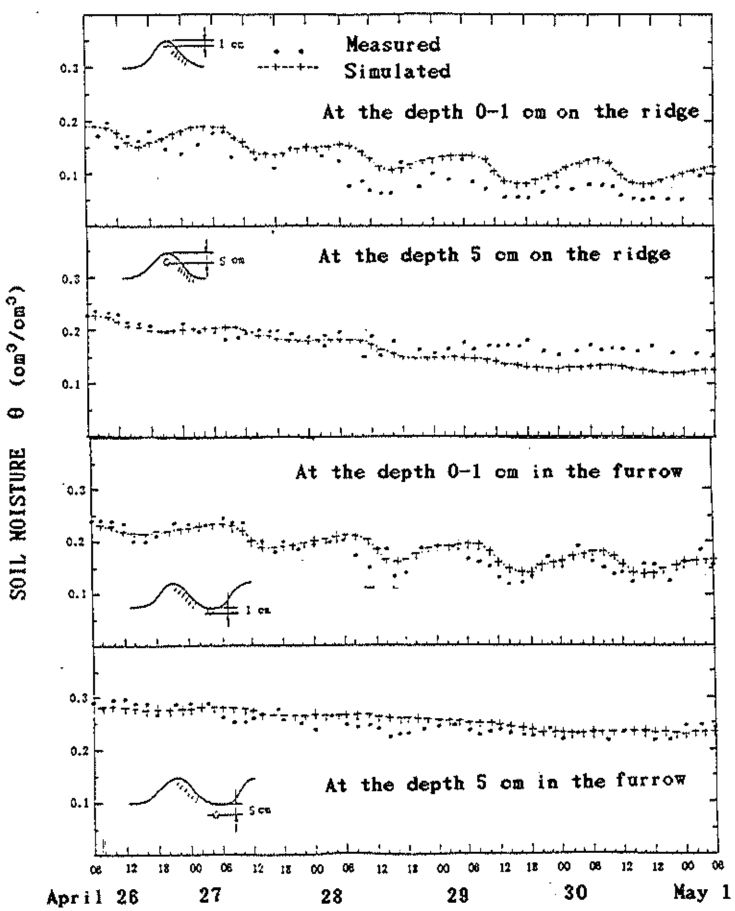

Fig. 9. The comparison of measured and calculated moisture content at the depth of 0-1 and 5 cm in the ridge and furrow

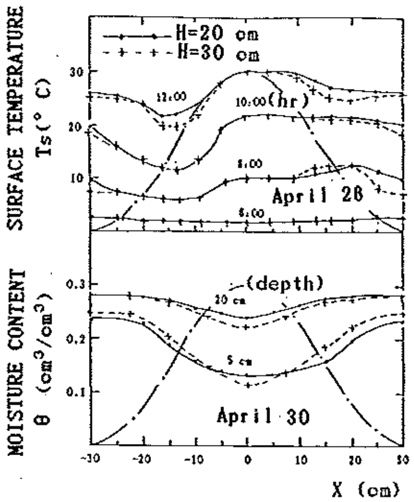

Fig. 10. The simulated soil temperature and moisture content as influenced by different depth of furrows

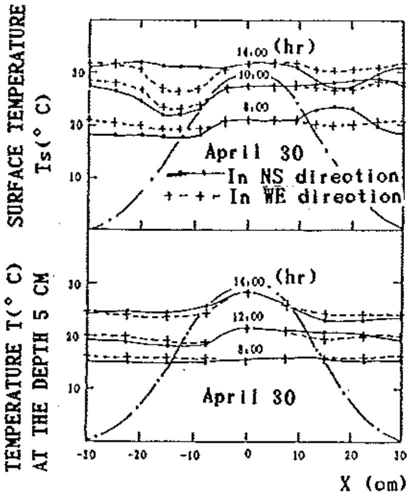

Fig. 11. The simulated soil temperature distribution as influenced by different animuth of furrows.

CONCLUTIONS

(1) A two-dimensional evaporation model was developed to predict the evaporation rate and the surface temperature on the seebed minimum-tilled or of ridge and furrow. (2) Based on the theory of simultaneous transfer of heat and moisture in porous media (Philip and de Vries, 1957) and the evaporation model developed by the authors, a simulation program for the influence of tillage operations on seedbed moisture and temperature behavior was compiled and validated by experiment field data. (3) Only the simulation of soil moisture and temperature as effected by ridge and furrow was discussed in the paper, however, the simulation program is expected to be generally useful in the study of different tillage practice and tillage implements.

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THE COMPUTER ANALOGY OF THE INTERACTION BETWEEN SOIL AND LUG

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ABSTRACT

A computer model for predicting the dynamic performances of a lug was developed according to the similarity between the measured curves of soil reaction on a lug and the curve of attenuate vibration. The model could be used in a wide range applications, and could be used for theortical analysis of the dynamic perfomance of rigid lugged wheel.

INTRODUCTION

The interaction between lug and soil is a important project in the feild of terramechanics. Many researchers,especially in China, Japan, and countries of South East Asia are doing research work on the interaction process, soil flow pattern under a lug or lugs, and the prediction of soil reaction on a lug. They are aware that the main problem of mechanization on paddy field is the mobility of agricultural vehicles. A pressing matter of the moment is to design a better wheel or tire that is suitable for agrotechnical demand, low use costs, and high efficiency.

It is already known that the horizontal and vertical reaction on a lug depend on the soil mechnical properties (water content, cohesion,internal friction angle, adhesion, etc.), the geometrical design of a lug (lug width,hight,angle, width on outtop, pattern of driving surface, and lug member), and the slippage. The reports from our laboratory. and others show that 1) the pattern of reported measurement curves are very similar and 2) the variations of soil reactions with rotating angle also are very similar.

THE VARIATIONAL PATTERN OF SOIL REACTION ON A LUG

It is well know that the lug motion is the combination of circular and forward motion, namely slipping rotation. During the interactive process of lug and soil, there are the normal reaction Fn and the tangential reaction Ft on the driving surface of a lug. The horizantal reaction Fp and the vertical reaction F could be expressed as:(Fig. 1)

$$F_p = F_n \sin(\theta' - \alpha) - F_t \cos(\theta' - \alpha) \qquad (1)$$

$$F_L = F_n \cos(\theta' - \alpha) + F_t \sin(\theta' - \alpha) \qquad (2)$$

where θ' is rotation angle and α is lug angle.

The normal reaction Fn is dependent on the cohesion, internal friction angle of soil, the angle between the soil surface and the driving surface of a lug, and shear modular J, while the tangential reaction Ft is dependent on the adhesion, soil-lug surface friction angle, and the tangential speed of the lug surfce.

The variational pattern of horizantal reaction Fp is from zero to uphill with increasing rotation angle θ', and reaches a the maximum about at lowest point (θ'=90 degree), then it will decrease slowly. The vertical reaction F_L goes up and down very quickly with the increasing rotation angle , and reaches the upmost point earlier than Fp. The F_L may be negative when the lug leaves soil.

In addition, the lug angle affects F_L significantly , but affects Fp only slightly when the slip is constant. F_L will upgrade with the increase of lug angle. Slip has an effect on the Fp, but almost no effect to the F_L when the lug angle is constant.

THE MODEL OF SOIL REACTION ON A LUG

Based on the theory of mechanical vibration, a linear system with one degree freedom is subjected to a unit impulse 1 (t) at t=0 (Fig. 2), the differential equation being

$$m\ddot{y} + c\dot{y} + ky = 1\delta(t) \tag{3}$$

Assume the initial conditions is $\dot{y}(0_-) = y(0_-) = 0$. The solutions are

$$y = k1\, e^{-\zeta pt} \sin(qt) \quad (\zeta < 1) \tag{4}$$

$$y = k2\, t e^{-pt} \quad (\zeta >= 1) \tag{5}$$

where $p^2 = k/m$, $q^2 = (1-\zeta^2)p^2$, ζ is resistance rate. The system will vibrate attenuately when ζ <1, and when ζ >=1, critical resistance or large resistance, there is a non-ibration attenuation. It is very interesting that the curves are very similar to the curves of the horizantal reaction Fp and the vertical reaction F_L on a lug as shown Fig. 3. The Fp and F_L could be expressed as

$$Fp(\theta) = Pmax * K1(i,\alpha) * e^{-K2(i,\alpha)\theta} \tag{6}$$

$$F_L(\theta) = Pmax * K3(i,\alpha) * Sin(K5\,\theta) * e^{-K4(i,\alpha)} \tag{7}$$

The many measurements show that other factors should also taken into account as follows. (1) The uprate of Fp(θ) is less than exponential uprate, while the downrate is more than exponential downrate. So the variational pattern of Fp(θ) is more similar to square exponent rate $exp(\theta^2)$. (2) The angle that the Fp(θ) gets maximum varies as lug angle α, and slip i, so the angle in Fp(θ) expression should be modified as $exp[-K_2(\theta-X)^2]$. (3) F_L (θ) goes down to zero usualy at about 0.75*

$(\theta_o - \theta_i)$. The angle cycle could be assumed as $1.5(\theta_o - \theta_i)$, then $K_5 = 360/(1.5(\theta_o - \theta_i))$.Now, the equations (6) and (7) could be rewrited as followings

$$Fp(\theta) = Pmax * \frac{2\theta}{AB} e^{-B\left(\frac{\theta - \alpha/B}{A}\right)^2} \tag{8}$$

$$F_L(\theta) = Pmax * \left(\frac{\alpha}{\alpha_p}\right) * \sqrt{2B} * Sin(D\theta) * e^{-B\left(\frac{\theta}{A}\right)} \tag{9}$$

where θ - the difference of actual rotate angle and into_soil angle θ_i, the range is from 0 to $(\theta_o - \theta_i)$, θ_o is out_soil angle.

P - maximum soil reaction on account of α_p .

α - lug angle.

A - $(\theta_o - \theta_i)/2$.

B - $(11\alpha/500i)^{\frac{1}{2}}$, i is slip (%).

D - $720/(3(\theta_o - \theta_i))$.

THE APPLICATIONS OF THE MODEL

PREDICTING SOIL REACTION FOR A LUG

The model could be used for predicting soil reaction Fp and F_L for a variety of lug angle θ and slip i in the same soil. Take the $\alpha_p = 25°$, for example, the parameters of the lug and soil are shown in Table 1,2, θ_i=50 , θ_o=130 ,A=40, D=3, and Pmax=195.71N by the method provided by reference [4],then

$$Fp(\theta) = 195.71 \frac{\theta}{20B} e^{-B\left(\frac{\theta - \alpha/B}{40}\right)^2} \tag{10}$$

$$F_L(\theta) = 195.71 \frac{\alpha\sqrt{2B}}{25} Sin(3\theta)\ e^{-B\frac{\theta}{40}} \tag{11}$$

The predictions of Fp,F_L and the comparision with measurements are shown in figure 4 . The relation coefficients of the prediction and measured curves are about 0.9.

Table 1 parameters

slip	lug angle	others
15.4 %	15	out radius R = 195 mm
25.2 %	26.5	lug high H = 10 mm
35.3 %	35	lug width D = 123 mm

Table 2 soil properties

kind	water content (%)	bulk density (g/cm)	cohesion (N/cm)	friction angle (degree)	shear modular
clay	52-58	1.65-1.70	0.3-0.51	4 - 7	1 - 1.36

PREDICTING PERFORMANCE FOR RIGID LUGGED WHEEL

One of the major advantages of the model is to provide an easy way of analysing the lugged wheel performances. Assume the mean thrust Fp.a and the mean lift F_L.a as followings

$$Fp.a = \frac{1}{\theta_o - \theta_i} \int_0^{\theta_o - \theta_i} Fp(\theta)\ d\theta \qquad (12)$$

$$F_L.a = \frac{1}{\theta_o - \theta_i} \int_0^{\theta_o - \theta_i} F_L(\theta)\ d\theta \qquad (13)$$

To integrate equations (12) and (13), then

$$Fp.a = \frac{P_{max}}{2B^2}[1 + (\alpha/A)(\pi/B)^{\frac{1}{2}}] \qquad (14)$$

$$F_L.a = Pmax * (\frac{\alpha}{\alpha_p}) \frac{3\pi\sqrt{2B}}{9B^2 + 4\pi^2} \qquad (15)$$

Assume the central point of soil reaction on a lug is in a third high of driving surface under the soil. The coordinates of the central point D are

$$X(\theta) = R_o \mathrm{Cos}\,\theta' - \frac{1}{3}R_o(\mathrm{Sin}\,\theta - \mathrm{Sin}\,\theta_i)\mathrm{Ctg}(\theta - \alpha)$$
$$Z(\theta) = R_o \mathrm{Sin}\,\theta' - \frac{1}{3}R_o(\mathrm{Sin}\,\theta - \mathrm{Sin}\,\theta_i)$$

The input moment $Mq(\theta)$,the mean input moment Mq.a and the efficiency of a lug are followings

$$Mq(\theta) = F_L(\theta) * X(\theta) + Fp(\theta) * Z(\theta) \qquad (16)$$

$$Mq.a = \frac{1}{\theta_o - \theta_i} \int_0^{\theta_o - \theta_i} Mq(\theta)\ d\theta \qquad (17)$$

$$\eta lug = Fp.a * R_o(1-i)/Mq.a. \qquad (18)$$

The prediction of Fp.a, Fl.a, Mq and Mq.a are very well accordant with the measurements. *The maximum lug efficiency* ηlug.max is varied with lug angle and slip. The lug angles are 15, 22, 26.5, 30, 35 degree, the maximum lug efficiencies occure at the slip of 12.5%, 15.0%, 16.5%, 18.0% and 19.0%, respectively. It is very interesting that all of the $Fp(\theta)$ curves are almost the same pattern and the maximum point of $Fp(\theta)$ curves are at about ten degree befor lowest point of lug

CONCLUSION

The model described has been developed on the basis of measurements and the reports from our laboratory. and others, and the analysis on the variational pattern of $Fp(\theta)$ and $F_L(\theta)$ with the lug angle and its slip.The model is simple and could be used for predicting and analysing the dynamic performance of lug or rigid lugged wheel.

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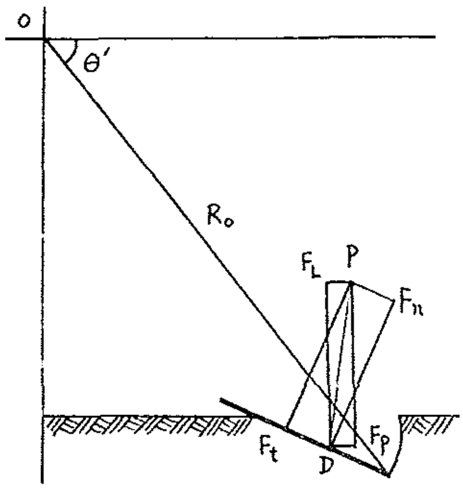


Fig. 1
Coordinate of a lug

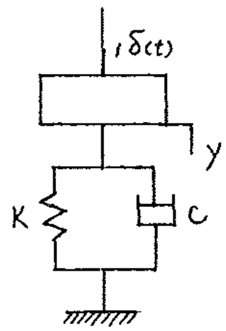


Fig. 2 linear system

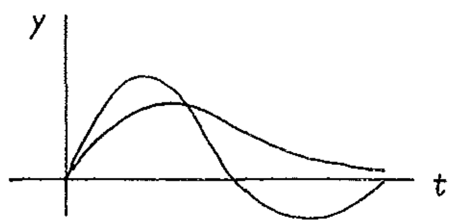
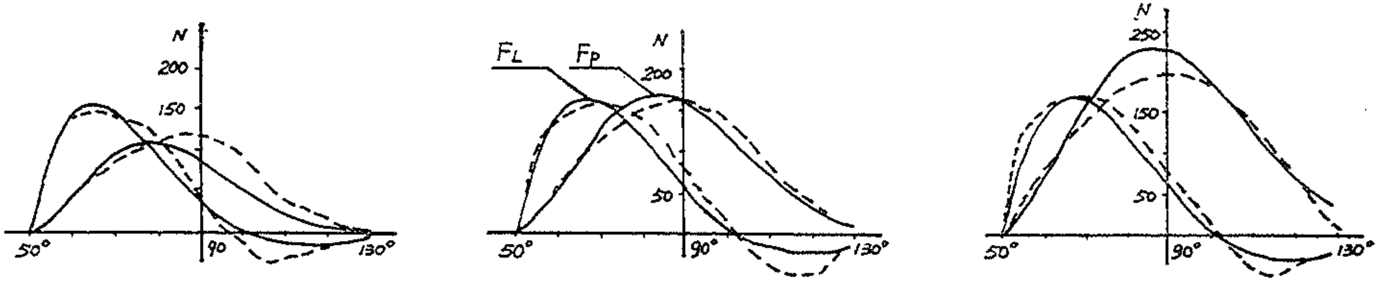


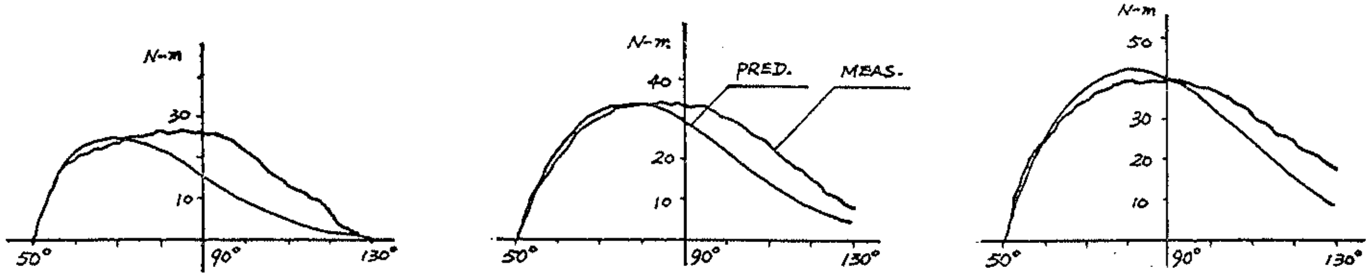
Fig.3 Vibration curves



Slip=15.4% Slip=25.2% Slip=35.3%

Soil Clay; Lug Angle=26.5 deg. ____ pred. — — — — Meas.

Fig.4 The Comparison of Fp, Fl predictions and measurements



Slip=15.4% Slip=25.2% Slip=35.3%

Soil=Clay, Lug Angle=26.5 deg.

Fig.5 The comparison of Mq predictions and measurements