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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 \textit{(Triticum aestivum L.)}/peas \textit{(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 weeder 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.

\textbf{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. 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 0.15 m 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.

REFERENCES


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 fresh 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.
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.

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, tests 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.
RESULTS AND DISCUSSION

DRAWN SUBSOILER Fig. 5 shows a displacement and stress field analyzed by FEM for a subsoiler movement 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
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 tractive 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 $\lambda$ 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.

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 $\alpha$ equal 0.52 rad to $\alpha$ 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 $\lambda$. When sludge was injected, both mean torque and draft were nearly constant over the range of $\lambda$ 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 $\lambda < 4.0$, 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 $\lambda$ of 6.5. However, at a $\lambda$ of 4.0 the total powers were the same because the power of 1.4 daW to inject the

![Fig. 6 Oscillogram showing recordings of experimental variables.](image)

![Fig. 7 Draft reduction as a function of operating speed and flow rate of injected sewage sludge.](image)

![Fig. 8 Cross section of soil path distributed by subsoiler.](image)
sludge was constant regardless of the value of \( \lambda \). For a \( \lambda < 4.0 \) 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,
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 $\lambda$ ranging from 2.5 to 6.5. At a $\lambda$ 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.

REFERENCES


THE DETERMINATION OF PLOW DRAUGHT FROM SOIL PENETRATION RESISTANCE

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¹Institute of Agricultural Mechanization, University of Agriculture, Szczecin (Poland)
²School of Agriculture, Jastrowie (Poland)

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: \( V = 1.8 \text{ ms}^{-1} \).

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

\[
K = K_0 + c \cdot v^2
\]

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 \( c \), which depends on the setting angle of the wing of the moldboard \( \theta \). 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.
The equation developed expressing this relationship is

\[ K = K_1 CI + K_2 \gamma v^2 (1 - \cos \theta_a) / g \]

where

- \( CI = \) cone index,
- \( K_1 \) and \( K_2 = \) empirical coefficients,
- \( \gamma = \) soil specific weight.

In both equations the effect of the moldboard shape on specific plowing resistance was expressed by only one parameter: the tail angle \( \theta_a \). 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 equipped 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-350. The recording equip-
ment was installed on field laboratory vehicle, driven alongside the tractor.

Table 1. Details of the plow bottoms

<table>
<thead>
<tr>
<th>Main parameters</th>
<th>KP</th>
<th>KR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load angle $\alpha$ (rad)</td>
<td>0.349</td>
<td>0.401</td>
</tr>
<tr>
<td>Cutting angle $\gamma_k$ (rad)</td>
<td>0.541</td>
<td>0.558</td>
</tr>
<tr>
<td>Setting angle $\theta_0$ (rad)</td>
<td>0.663</td>
<td>0.698</td>
</tr>
<tr>
<td>Length of the share $B$ (m)</td>
<td>0.523</td>
<td>0.580</td>
</tr>
<tr>
<td>Tail angle $\theta_s$ (rad)</td>
<td>0.785</td>
<td>0.773</td>
</tr>
<tr>
<td>Slope of the moldboard $L$ (m)</td>
<td>0.390</td>
<td>0.245</td>
</tr>
<tr>
<td>Height of the moldboard $H$ (m)</td>
<td>0.415</td>
<td>0.425</td>
</tr>
<tr>
<td>Steepness of the moldboard $L/H$</td>
<td>0.940</td>
<td>0.580</td>
</tr>
</tbody>
</table>

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 mm² and 323 mm² 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

<table>
<thead>
<tr>
<th>Particle size distribution (%)</th>
<th>Silty fine sand</th>
<th>Sandy clay</th>
<th>Clay</th>
</tr>
</thead>
<tbody>
<tr>
<td>GBL</td>
<td>GL</td>
<td>GC</td>
<td></td>
</tr>
<tr>
<td>&gt; 1 mm</td>
<td>2</td>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td>1 - 0.1 mm</td>
<td>75</td>
<td>21</td>
<td>32</td>
</tr>
<tr>
<td>0.1 - 0.02 mm</td>
<td>18</td>
<td>48</td>
<td>22.5</td>
</tr>
<tr>
<td>&lt; 0.02 mm</td>
<td>5</td>
<td>30</td>
<td>45</td>
</tr>
<tr>
<td>Water content (% W/W)</td>
<td>14.6</td>
<td>14.4</td>
<td>15.3</td>
</tr>
<tr>
<td>Bulk density</td>
<td>1.35</td>
<td>1.59</td>
<td>1.56</td>
</tr>
<tr>
<td>Soil surface</td>
<td>grass</td>
<td>stubble</td>
<td>bare</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Type of soil</th>
<th>Type of bottom</th>
<th>Depth of plowing (m)</th>
<th>Plowing draught (kN)</th>
<th>Sectional area of slice (m²)</th>
<th>Specific draught speed (MPa)</th>
<th>Actual speed (ms⁻¹)</th>
<th>Cone index</th>
</tr>
</thead>
<tbody>
<tr>
<td>FOSA</td>
<td>FA</td>
<td>0.21</td>
<td>3.26</td>
<td>0.08</td>
<td>4.1</td>
<td>1.9</td>
<td>0.68</td>
</tr>
<tr>
<td>GBL</td>
<td>KP</td>
<td>0.24</td>
<td>3.60</td>
<td>0.09</td>
<td>4.0</td>
<td>1.8</td>
<td>0.73</td>
</tr>
<tr>
<td></td>
<td>GBL</td>
<td>0.26</td>
<td>2.64</td>
<td>0.083</td>
<td>3.2</td>
<td>1.8</td>
<td>0.76</td>
</tr>
<tr>
<td></td>
<td>KR</td>
<td>0.17</td>
<td>2.37</td>
<td>0.055</td>
<td>4.3</td>
<td>1.9</td>
<td>0.61</td>
</tr>
<tr>
<td></td>
<td>GBL</td>
<td>0.24</td>
<td>4.62</td>
<td>0.072</td>
<td>6.4</td>
<td>1.8</td>
<td>0.74</td>
</tr>
<tr>
<td></td>
<td>GBL</td>
<td>0.27</td>
<td>5.64</td>
<td>0.078</td>
<td>7.2</td>
<td>1.8</td>
<td>0.78</td>
</tr>
<tr>
<td></td>
<td>KP</td>
<td>0.20</td>
<td>1.45</td>
<td>0.075</td>
<td>1.9</td>
<td>1.6</td>
<td>0.65</td>
</tr>
<tr>
<td></td>
<td>GBL</td>
<td>0.23</td>
<td>1.50</td>
<td>0.086</td>
<td>1.7</td>
<td>1.5</td>
<td>0.67</td>
</tr>
<tr>
<td></td>
<td>GBL</td>
<td>0.28</td>
<td>2.77</td>
<td>0.115</td>
<td>2.4</td>
<td>1.5</td>
<td>0.75</td>
</tr>
<tr>
<td></td>
<td>KP</td>
<td>0.19</td>
<td>1.41</td>
<td>0.073</td>
<td>1.9</td>
<td>1.5</td>
<td>0.45</td>
</tr>
<tr>
<td></td>
<td>GBL</td>
<td>0.23</td>
<td>2.43</td>
<td>0.095</td>
<td>2.6</td>
<td>1.5</td>
<td>0.67</td>
</tr>
<tr>
<td></td>
<td>GBL</td>
<td>0.28</td>
<td>3.26</td>
<td>0.111</td>
<td>2.9</td>
<td>1.5</td>
<td>0.74</td>
</tr>
<tr>
<td></td>
<td>KP</td>
<td>0.19</td>
<td>4.30</td>
<td>0.07</td>
<td>6.1</td>
<td>1.7</td>
<td>1.23</td>
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<tr>
<td></td>
<td>GBL</td>
<td>0.23</td>
<td>3.85</td>
<td>0.082</td>
<td>4.7</td>
<td>1.7</td>
<td>1.23</td>
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<tr>
<td></td>
<td>GBL</td>
<td>0.28</td>
<td>7.50</td>
<td>0.11</td>
<td>6.8</td>
<td>1.6</td>
<td>1.22</td>
</tr>
<tr>
<td></td>
<td>KP</td>
<td>0.18</td>
<td>4.70</td>
<td>0.06</td>
<td>7.9</td>
<td>1.8</td>
<td>1.21</td>
</tr>
<tr>
<td></td>
<td>GBL</td>
<td>0.21</td>
<td>5.60</td>
<td>0.075</td>
<td>7.5</td>
<td>1.7</td>
<td>1.24</td>
</tr>
<tr>
<td></td>
<td>GBL</td>
<td>0.27</td>
<td>6.30</td>
<td>0.099</td>
<td>6.4</td>
<td>1.7</td>
<td>1.22</td>
</tr>
</tbody>
</table>
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 coefficients $K_1$, $K_2$ (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.

REFERENCES

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

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2Department of Mechanical Engineering, Institute Hassan II, Rabat (Morocco).

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 theoretical 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, saving 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:

\[ x_A = v \cdot t + R \cos \omega t \]
\[ y_A = R \sin \omega t \]  \hspace{1cm} (1)

and

\[ x_B = v \cdot t - R \cos \omega t \]
\[ y_B = -R \sin \omega t \]  \hspace{1cm} (2)

with

- \( R \) = rotor radius;
- \( t \) = time;
- \( v \) = machine forward velocity;
- \( \omega \) = 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 instantaneous 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 \( \vec{U} = \omega \cdot \vec{R} \).

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

\[ \vec{v} = \omega \cdot \vec{a} \]  \hspace{1cm} (3)

From this, knowing that \( \vec{v} \) and \( \omega \) are constants, it follows that IC always lies on a straight line ox' parallel to x-axis, with \( y = \alpha \) 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:

\[ x = a \cdot (t - \lambda \sin \omega t) \]
\[ y = a \cdot (1 - \lambda \cos \omega t) \]  \hspace{1cm} (4)

with

\[ \lambda = \frac{U}{v} \]
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 $\lambda$ 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 $\lambda$ corresponds to closer passages of rotating tines in the soil and thus ensures a greater pulverization. On the other hand, a decrease of $\lambda$ 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 $\lambda$: 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 1983, 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 × 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
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 suddenly 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 (%).

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Spring-tine cultivator</th>
<th>Rotary cultivator ($\lambda = 2.34$)</th>
<th>Rotary cultivator ($\lambda = 3.77$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before sowing</td>
<td>After sowing</td>
<td>Before sowing</td>
</tr>
<tr>
<td>0 to 1</td>
<td>42.2</td>
<td>31.4</td>
<td>30.9</td>
</tr>
<tr>
<td>1 to 2</td>
<td>21.9</td>
<td>19.8</td>
<td>6.7</td>
</tr>
<tr>
<td>2 to 3</td>
<td>15.4</td>
<td>14.4</td>
<td>4.7</td>
</tr>
<tr>
<td>3 to 4</td>
<td>18.3</td>
<td>14.5</td>
<td>3.0</td>
</tr>
<tr>
<td>4 to 5</td>
<td>19.8</td>
<td>11.3</td>
<td>5.0</td>
</tr>
<tr>
<td>5 to 6</td>
<td>15.5</td>
<td>14.8</td>
<td>5.8</td>
</tr>
<tr>
<td>6 to 7</td>
<td>17.2</td>
<td>13.2</td>
<td>6.4</td>
</tr>
<tr>
<td>7 to 8</td>
<td>15.4</td>
<td>11.4</td>
<td>5.1</td>
</tr>
</tbody>
</table>

From Table I, it appears that porosity resulting from the passage of a rotary tiller with $\lambda = 3.77$ is considerably less than that of a rotary tiller with $\lambda = 2.34$. 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 $\lambda = 2.34$ 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 $\lambda = 3.77$. 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:

$$C = 2\sqrt{\frac{S}{\pi}}$$

with $S$ the area and $P$ the perimeter.

For elongated pores, ($L = 10$), 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 constituted of too smaller sized clods presents the risk of creating soil crusts, in certain circumstances.

ACKNOWLEDGMENTS

The authors are grateful to Mrs J. Bock for her help in revising the English text.

REFERENCES


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 $\lambda = 3.77$ and 2.34

Fig. 4. Area distribution of pores after the passage of rotary harrow ($\lambda = 2.34$), 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 \( \mu \text{m} \), 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 cm³ 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.

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. Particularly 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.

![Graph A](image)

**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 \(\mu\)m, 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. 3B).
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 mouldboard 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.

REFERENCES

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 T0 (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 T0 (coleoptilar) and Ti (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).
- 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 penetrometer 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
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 T0 tillers. Whereas the prototype drill, both in the conventional and minimum tillage treatments, resulted in the lowest percentage of plants with T0 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.

REFERENCES


Fig. 1. Average soil cone strength in the five treatments compared. L1 (O--O); L2 (+--t); L3 (---*); L4 (X----X); L5 (---*).

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

<table>
<thead>
<tr>
<th>Soil Depth (cm)</th>
<th>Treatments</th>
<th>LSD</th>
<th>P &lt; 0.05</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L1</td>
<td>L2</td>
<td>L3</td>
</tr>
<tr>
<td>0-10</td>
<td>397</td>
<td>282</td>
<td>327</td>
</tr>
<tr>
<td></td>
<td>c</td>
<td>a</td>
<td>b</td>
</tr>
<tr>
<td>10-20</td>
<td>622</td>
<td>476</td>
<td>502</td>
</tr>
<tr>
<td></td>
<td>c</td>
<td>ab</td>
<td>b</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Treatments</th>
<th>LSD</th>
<th>P &lt; 0.05</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L1</td>
<td>L2</td>
<td>L3</td>
</tr>
<tr>
<td>0</td>
<td>9.9</td>
<td>9.0</td>
<td>8.5</td>
</tr>
<tr>
<td>5</td>
<td>16.9</td>
<td>16.6</td>
<td>17.0</td>
</tr>
<tr>
<td>10</td>
<td>17.0</td>
<td>17.6</td>
<td>17.7</td>
</tr>
<tr>
<td>15</td>
<td>16.7</td>
<td>17.3</td>
<td>17.6</td>
</tr>
<tr>
<td>20</td>
<td>17.1</td>
<td>17.3</td>
<td>17.1</td>
</tr>
</tbody>
</table>
Table III. Influence of tillage system and cereal drill on spring barley growth

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

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 chisel. 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, \( f_0 \delta(x) \) 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 \( f_0 \) 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 constraint 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 chisel 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 its 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.

REFERENCES

Vertical force measurement

Instrumented chisel

Strain Gages which measure bending moment acting on the chisel as it moves through the soil.

Replaceable cutting edge

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

![Graph showing force distribution against depth](image)

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 predominantly 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 = 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 ≤ 2.5:1) with the passive slip planes coinciding, causing an increase in surface disturbance and penetration resistance.

iii) "Diamond failure" (ratio ≤ 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.

iv) 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 Renado 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.

REFERENCES


i) WIDE FOOT (75mm)

SOIL SURFACE
PASSIVE FAILURE
ACTIVE SOIL WEDGE
SLIP PLANE

ii) MEDIUM FOOT (50mm)

PASSIVE FAILURE
SLIP PLANE
COMPRESSIVE FAILURE

iii) NARROW FOOT (25mm)

COMPRRESSIVE FAILURE

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

---

i) INDEPENDENT PASSIVE

ii) INTERACTIVE PASSIVE

iii) "DIAMOND" FAILURE

iv) COMPRESSIVE

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)
Figure 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.

### Table 1: The change in soil strength with increasing furrow press weight measured as percentage sinkage of a tractor wheeling.

<table>
<thead>
<tr>
<th>Weight per ring (kg)</th>
<th>Sandy Loam</th>
<th>Clay Loam</th>
</tr>
</thead>
<tbody>
<tr>
<td>86</td>
<td>3.55</td>
<td>5.63</td>
</tr>
<tr>
<td>112</td>
<td>2.87</td>
<td>4.45</td>
</tr>
<tr>
<td>138</td>
<td>12.18</td>
<td>3.39</td>
</tr>
</tbody>
</table>

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 loaded (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 redistribution 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 transducers (Horn, 1980) measured vertical stress \( \sigma_v \), or horizontal stress \( \sigma_h \) 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 \( \sigma_v \) and \( \sigma_h \) are shown in relation to speed. \( \sigma_v \text{ max} \) 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 \( \sigma_v \text{ max} \), while at a lower water content \( \sigma_v \text{ max} \) was less at the higher speeds. At 35 cm depth, an increase in speed resulted in a decrease of \( \sigma_v \text{ max} \). This decrease with speed also occurred for the \( \sigma_h \) values at 20 cm.

Figure 3 shows the change of \( \sigma_h/\sigma_v \) 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 (\( \Theta_g \)) at 20 cm depth, and decreased with speed. Expressing the mean rut depth (mr) as a logarithm, we obtained the following Eqn (1).

\[
\log \text{mr} \ (\text{cm}) = 0.0485 \ \Theta_g \ (\% \ w/w) - 0.0046 \ \text{speed (km h}^{-1}) - 0.1089 \ (1)
\]

\( r^2 = 0.817 \quad P = 0.004 \)

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 \( K_s \) 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 60 % 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 be considered, 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.
REFERENCES


Fig. 1: Changes of vertical stresses $\sigma_v$ (MPa $\times 10^{-1}$) with time for 3 kinds of speed (water content $\sim$20% by weight).
Fig. 3: Variation of $G_h/G_v$ 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 1984/85 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 measured 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 cm³ 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 (Greacen et al., 1969). Although the dry bulk density returned to its original undisturbed 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:

$$Y = 0.012 + 0.019X$$

$r = 0.76 ** (P > 0.01)$

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 meteorological 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.

REFERENCES


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/sub-surface/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 RABA-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-25CC, Haylock Triple Task, Howard-Pereplow, 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 of 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 RABA-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 Balatonszárazd "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°/
- 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 found that

- on medium heavy soils rake angles of 25-30° 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°/;
- 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 across section, rise in surface level, the 200 mm wing width is to be considered the most favourable;
- the size of area loosened 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, i.e. on medium heavy soils, the 25-300 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 loosener can be improved, while their energy consumption can be reduced.

REFERENCES


The data of working elements

Table I.

<table>
<thead>
<tr>
<th>Tool mark</th>
<th>Rake angle /degree/</th>
<th>Width of shear or wing /mm/</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>20</td>
<td>60</td>
</tr>
<tr>
<td>3</td>
<td>25</td>
<td>60</td>
</tr>
<tr>
<td>4</td>
<td>30</td>
<td>60</td>
</tr>
<tr>
<td>5</td>
<td>35</td>
<td>60</td>
</tr>
<tr>
<td>6</td>
<td>30</td>
<td>100</td>
</tr>
<tr>
<td>A</td>
<td>30</td>
<td>200</td>
</tr>
<tr>
<td>B</td>
<td>30</td>
<td>300</td>
</tr>
<tr>
<td>C</td>
<td>30</td>
<td>200</td>
</tr>
<tr>
<td>D</td>
<td>30</td>
<td>300</td>
</tr>
</tbody>
</table>
Cross section of different share (wing) widths (60 - 300 mm)
Rake angle 30°

Wing width 60 mm Working speed 7.9 km h⁻¹
Wing width 100 mm Working speed 8.3 km h⁻¹
Wing width 200 mm Working speed 8.1 km h⁻¹
Wing width 300 mm Working speed 7.7 km h⁻¹

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

Rake angle 20° Working speed 8.5 km h⁻¹

Rake angle 25° Working speed 8.4 km h⁻¹

Rake angle 30° Working speed 7.9 km h⁻¹

Rake angle 35° Working speed 7.9 km h⁻¹

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

Symbol:
- Share № 2
- Share № 3
- Share № 4
- Share № 5
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 of these 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 to float 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 Reese developed the calculation of passive soil resistance in 1966[3] During experiments conducted by Gee-Clough and Chancellor 1976 [4], Zhang and Shao 1984 [5] Deng and 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 elliptical 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,
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 special vehicle equipped with boat and lug wheels. The boat body is used as floating and bearing device with very low contact pressure ($2 \text{ - } 8 \text{ kpa}$) 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° 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 simultaneously 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

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Unit weight ($\text{kN/m}^3$)</th>
<th>Cohesion (kpa)</th>
<th>Internal friction angle</th>
<th>Soil-metal friction angle</th>
<th>moisture content(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAND</td>
<td>14.7</td>
<td>-</td>
<td>28°</td>
<td>18.5°</td>
<td>--</td>
</tr>
<tr>
<td>CLAY</td>
<td>16.8</td>
<td>4</td>
<td>5°</td>
<td>2.5°</td>
<td>56</td>
</tr>
<tr>
<td>P A D DY S O I L</td>
<td>17.2</td>
<td>2.5</td>
<td>13°</td>
<td>10.0°</td>
<td>37</td>
</tr>
</tbody>
</table>

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 $\beta$ and lower boundary circle were found in wet clay and paddy soil at 15.2-25.2% 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 preceding cavity giving an interruption to the flow line of soil particles, and the angle between flow line and horizontal line being smaller than $45^{\circ}/2$, 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 TRL 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](image1)

![Fig. 2 Soil flow beneath single lug (left) and 6 lugs (right) in clay at 25.2% slip](image2)
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 \( K_1 = \frac{F_{mp}}{F_{sp}} \), \( K_2 = \frac{W_{mp}}{W_{sp}} \). \( F_{mp} \) 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 meanted 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 \( K_2 \) were derived by means of the regressive treatment of measured datum.

\[
K_1 = 1.2858 i^{-0.1526} (0.8495-0.001717\phi)(0.64+0.0489L/h)(0.8495-0.01019\phi)
\]

\[
K_2 = 1.3559 i^{-0.1547} (0.9027-0.004253\phi)(0.571+0.06361L/h)(0.9641-0.01407\phi)
\]

The correlation coefficient was 0.9030 for \( K_1 \) formula and 0.8847 for \( K_2 \) 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 \( \alpha \), the distance between two adjacent lug \( L \) and height of lug \( h \), and internal friction angle \( \phi \) are known.

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 0.2 m/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.

REFERENCES


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 ; \( Y = -4.67 \text{ Bd} + 12.05 \) , \( r = 0.60 \)
1986 ; \( Y = -6.22 \text{ Bd} + 12.83 \) , \( r = 0.55 \)
1987 ; \( Y = 1.35 \text{ Bd} + 0.61 \) , \( r = 0.15 \)

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 significantly 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.

\[
\text{RYI} = \frac{Y_d - Y_c}{Y_c} \times 100
\]

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

**Table 1. Effect of tillage and irrigation treatments on grain yield of wheat.**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Grain Yield (Mg ha(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1985</td>
</tr>
<tr>
<td><strong>Tillage</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Irrigation intervals</strong></td>
<td>(day)</td>
</tr>
<tr>
<td>Subsoiling</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>5.31</td>
</tr>
<tr>
<td>14</td>
<td>4.68</td>
</tr>
<tr>
<td>21</td>
<td>4.32</td>
</tr>
<tr>
<td>Chiselling</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>5.00</td>
</tr>
<tr>
<td>14</td>
<td>4.76</td>
</tr>
<tr>
<td>21</td>
<td>3.97</td>
</tr>
<tr>
<td>Conventional Till.</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>4.38</td>
</tr>
<tr>
<td>14</td>
<td>4.00</td>
</tr>
<tr>
<td>21</td>
<td>3.61</td>
</tr>
<tr>
<td><strong>L.S.D</strong></td>
<td></td>
</tr>
<tr>
<td>(5%)</td>
<td></td>
</tr>
<tr>
<td>Tillage</td>
<td>0.52</td>
</tr>
<tr>
<td>Irrigation</td>
<td>0.40</td>
</tr>
<tr>
<td>Till Vs Irr.</td>
<td>NS</td>
</tr>
</tbody>
</table>

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.

![Graph showing infiltration rate](image)

**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).

![Graph showing bulk density](image)

**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 I1, I2 and Ia 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 P2O5 and 60 kg K2O 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.

**REFERENCES**


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 strengths 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

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil texture</td>
<td>Sandloam</td>
</tr>
<tr>
<td>Soil depth</td>
<td>250 - 300 mm</td>
</tr>
<tr>
<td>Clay content</td>
<td>8 %</td>
</tr>
<tr>
<td>Stone (&gt; 2 mm) content</td>
<td>44.6 %</td>
</tr>
<tr>
<td>Water content at -10 kPa</td>
<td>11.25 % m/v</td>
</tr>
<tr>
<td>Soil pH (KCl)</td>
<td>5.0</td>
</tr>
</tbody>
</table>

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 dia pen and a 30° 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 m² 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 (Wilkinson, 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.

REFERENCES


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.

<table>
<thead>
<tr>
<th>Thickness</th>
<th>Wedge slope</th>
<th>Coulter radius</th>
</tr>
</thead>
<tbody>
<tr>
<td>nominal, mm</td>
<td>actual, mm</td>
<td>mm</td>
</tr>
<tr>
<td>8</td>
<td>7.2</td>
<td>0.12</td>
</tr>
<tr>
<td>8</td>
<td>7.6</td>
<td>0.25</td>
</tr>
<tr>
<td>12</td>
<td>10.5</td>
<td>0.12</td>
</tr>
<tr>
<td>12</td>
<td>11.3</td>
<td>0.25</td>
</tr>
</tbody>
</table>

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. 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>
<thead>
<tr>
<th>Soil</th>
<th>Bulk density*, Mg/m³</th>
<th>Moisture content*, %</th>
<th>Cone index*, MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Norfolk sandy loam</td>
<td>0.72/0.17/0.11</td>
<td>1.62</td>
<td>0.07</td>
</tr>
<tr>
<td>Decatur clay loam</td>
<td>0.27/0.43/0.30</td>
<td>1.40</td>
<td>0.12</td>
</tr>
</tbody>
</table>

* 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.

REFERENCES


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](image)

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](image)
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>
<thead>
<tr>
<th>Implement</th>
<th>Soil type</th>
<th>Working width, m</th>
<th>Work rate, ha/h</th>
<th>Power consumption, kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mouldboard plough</td>
<td>Loam</td>
<td>2.40</td>
<td>0.83</td>
<td>28 nil 28</td>
</tr>
<tr>
<td>SCAE prototype</td>
<td>Loam</td>
<td>2.40</td>
<td>0.80</td>
<td>26 18 44</td>
</tr>
<tr>
<td>SCAE prototype</td>
<td>Sandy clay</td>
<td>2.40</td>
<td>0.75</td>
<td>28 20 48</td>
</tr>
</tbody>
</table>

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>
<thead>
<tr>
<th>Cultivation system (No. of passes in brackets)</th>
<th>Straw disposal method</th>
<th>Fuel consumption, l/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plough</td>
<td></td>
<td>Individual operations</td>
</tr>
<tr>
<td>Secondary cultivator (3)</td>
<td>chopped</td>
<td>24.4</td>
</tr>
<tr>
<td>Drill, roll</td>
<td></td>
<td>16.0</td>
</tr>
<tr>
<td>Shallow plough</td>
<td>chopped</td>
<td>14.9</td>
</tr>
<tr>
<td>Secondary cultivator (3)</td>
<td></td>
<td>15.7</td>
</tr>
<tr>
<td>Drill, roll</td>
<td></td>
<td>6.5</td>
</tr>
<tr>
<td>Disc/tine (2)</td>
<td>removed</td>
<td>20.6</td>
</tr>
<tr>
<td>Secondary cultivator (2)</td>
<td>burnt stubble</td>
<td>9.2</td>
</tr>
<tr>
<td>Drill, roll</td>
<td></td>
<td>6.4</td>
</tr>
<tr>
<td>SCAE prototype</td>
<td>chopped</td>
<td>18.2</td>
</tr>
<tr>
<td>Secondary cultivator (2)</td>
<td></td>
<td>10.6</td>
</tr>
<tr>
<td>Drill, roll</td>
<td></td>
<td>6.6</td>
</tr>
</tbody>
</table>

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

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 (Chithey 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° 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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9. Lu H.Z.; Shao Y.J. Experimental research on the soil flow and soil reaction beneath lugs of powered wheel, Proceedings 9th ISTVS Int. Conf. Barcelona Spain 1987


11. Ou Y.G.; Shao Y.J. A study on the motion resistance of the floating body of boat type tractor, Journal South China Agric. College, 1984, 5(1) 1-10
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 without 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)](image)

**SEMI-EMPIRICAL FORMULA FOR PREDICTING SLIDING RESISTANCE OF SLIDING BOAT**

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

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

where $R_S$ is the sliding resistance in N, $k_1$ and $k_2$ are the resistance coefficients, according to statistical regression $k_1 = -68 + 4300p_0$, $k_2 = 0.015 - 0.288v$ is the speed of boat in m/s, $A$ is contact area of boat with soil in cm², $c_a$ is soil adhesion in kpa, $p_0$ is contact pressure of boat on soil in kpa, and $\delta$ 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,

$$P_s = \frac{2(A_0 - A_f) \tau}{d + h} \cot \left[ \tan^{-1} \left( \frac{d + D}{d + h} \right) \right]$$

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

where $v$, $t$ - forward speed (m/s) and time (s), $\tau$ - shear (kpa), $A_0$, $A_f$ - initial and final contact area (cm²), $D$, $d$, $\alpha$ - 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.

P.O. AINA

Faculty of Agriculture, Department of Soil Science, Obafemi Awolowo University, Ile-Ife, (Nigeria).

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. However, 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 continuous 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 0.5 kg a.i. ha⁻¹; continuous conventional tillage (CT) involving moldboard plowing followed by disc harrowing to a depth of 15 cm; 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 C₂N₄, C₂N₂, C₁N₁, C₂N₂, C₄N₄, and CT and along the cropping systems of corn-cowpeas, cowpeas-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 and cowpea-corn rotations than under continuous corn or cowpea.

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 18 cm h⁻¹ to 9.8, 5.0, 6.2, 3.8 and 2.5 cm h⁻¹ in the C2N4, C2N2, C1M1, C4N4, and CT respectively. Infiltration was enhanced by cropping in the order 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 content 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 occurring 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 turnover (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 NWD 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.

REFERENCES

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

<table>
<thead>
<tr>
<th>Tillage</th>
<th>O.M. %</th>
<th>Total Porosity m⁻³</th>
<th>MWD cm</th>
<th>Infilt. rate 1 cm h⁻¹</th>
<th>Moisture retention (g g⁻¹) at indicated matric potentials (MPa):</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Initial</td>
<td>3.18</td>
<td>0.49</td>
<td>1.25</td>
<td>42.0</td>
<td>39.2</td>
</tr>
<tr>
<td>1986</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>37.9</td>
</tr>
<tr>
<td>NT</td>
<td>2.95</td>
<td>0.47</td>
<td>1.19</td>
<td>18.2</td>
<td>31.3</td>
</tr>
<tr>
<td>C1N1</td>
<td>1.96</td>
<td>0.44</td>
<td>0.75</td>
<td>6.2</td>
<td>29.9</td>
</tr>
<tr>
<td>C2M2</td>
<td>1.89</td>
<td>0.43</td>
<td>0.68</td>
<td>5.0</td>
<td>32.6</td>
</tr>
<tr>
<td>C2N4</td>
<td>2.25</td>
<td>0.45</td>
<td>0.88</td>
<td>9.8</td>
<td>29.2</td>
</tr>
<tr>
<td>CN4</td>
<td>1.85</td>
<td>0.42</td>
<td>0.62</td>
<td>3.8</td>
<td>28.9</td>
</tr>
<tr>
<td>CT</td>
<td>1.35</td>
<td>0.39</td>
<td>0.48</td>
<td>2.5</td>
<td>28.9</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Cropping sequence</th>
<th>NT 1st 2nd</th>
<th>C1N1 1st 2nd</th>
<th>C2M2 1st 2nd</th>
<th>C2N4 1st 2nd</th>
<th>CN4 1st 2nd</th>
<th>CT 1st 2nd</th>
<th>LSD (0.05)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1982</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corn-Cowpea</td>
<td>3.17 0.83</td>
<td>3.12 0.60</td>
<td>3.16 0.76</td>
<td>3.15 0.82</td>
<td>3.18 0.79</td>
<td>3.15 0.83</td>
<td>0.46 0.16</td>
</tr>
<tr>
<td>Cowpea-Corn</td>
<td>0.78 3.11</td>
<td>0.75 3.14</td>
<td>0.74 3.08</td>
<td>0.78 3.01</td>
<td>0.75 3.05</td>
<td>0.69 3.02</td>
<td>0.14 0.43</td>
</tr>
<tr>
<td>Corn-Corn</td>
<td>3.20 3.06</td>
<td>3.21 3.08</td>
<td>3.12 3.01</td>
<td>3.15 3.07</td>
<td>3.18 3.02</td>
<td>3.12 3.00</td>
<td>0.39 0.42</td>
</tr>
<tr>
<td>Cowpea-Cowpea</td>
<td>0.79 0.87</td>
<td>0.72 0.81</td>
<td>0.68 0.74</td>
<td>0.72 0.80</td>
<td>0.68 0.79</td>
<td>0.70 0.78</td>
<td>0.16 0.18</td>
</tr>
<tr>
<td>1984</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corn-Cowpea</td>
<td>3.08 0.82</td>
<td>2.56 0.71</td>
<td>2.64 0.68</td>
<td>2.74 0.76</td>
<td>2.39 0.63</td>
<td>2.24 0.65</td>
<td>0.23 0.10</td>
</tr>
<tr>
<td>Cowpea-Corn</td>
<td>0.70 2.98</td>
<td>0.62 2.44</td>
<td>0.66 2.62</td>
<td>0.69 2.57</td>
<td>0.58 2.21</td>
<td>0.53 2.18</td>
<td>0.08 0.15</td>
</tr>
<tr>
<td>Corn-Corn</td>
<td>2.96 7.68</td>
<td>2.18 7.07</td>
<td>2.51 2.32</td>
<td>2.42 2.29</td>
<td>2.23 2.14</td>
<td>2.03 1.92</td>
<td>0.19 0.23</td>
</tr>
<tr>
<td>Cowpea-Cowpea</td>
<td>0.72 0.79</td>
<td>0.57 0.59</td>
<td>0.62 0.68</td>
<td>0.59 0.65</td>
<td>0.56 0.58</td>
<td>0.52 0.56</td>
<td>0.10 0.12</td>
</tr>
<tr>
<td>1986</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corn-Cowpea</td>
<td>2.87 0.79</td>
<td>2.17 0.62</td>
<td>2.19 0.58</td>
<td>2.48 0.68</td>
<td>1.80 0.58</td>
<td>1.74 0.53</td>
<td>0.18 0.08</td>
</tr>
<tr>
<td>Cowpea-Corn</td>
<td>0.75 2.70</td>
<td>0.58 1.79</td>
<td>0.51 1.94</td>
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<td>0.38 0.44</td>
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</tr>
</tbody>
</table>


---

**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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(2) Agronomy Institute, Faculty of Agriculture, University of Perugia (Italy)
(3) Agricultural Engineering Institute, Faculty of Agriculture, University of Perugia (Italy)

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 ploughing);
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 scarce 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 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 which 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 cm$^2$.

Fig. 5 - Penetration resistance profile on different dates.
Fig. 6 - Penetration resistance and moisture mean values after different treatments.

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

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

<table>
<thead>
<tr>
<th>ATTEMBERG LIMITS</th>
<th>ORGANIC MATTER</th>
</tr>
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<tr>
<td>L.L.</td>
<td>P.L.</td>
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<tr>
<td>DEEP PLOUGHING</td>
<td>52</td>
</tr>
<tr>
<td>MINIMUM TILLAGE</td>
<td>59</td>
</tr>
</tbody>
</table>

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 mean ± standard error.**

<table>
<thead>
<tr>
<th>Tillage methods</th>
<th>Effective field-work capacity</th>
<th>Fuel consumption</th>
<th>Yield (standard moisture)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ha/h</td>
<td>kg/ha</td>
<td>kg/ha</td>
</tr>
<tr>
<td>Deep ploughing (.45 m)</td>
<td>.31 ± .01</td>
<td>72.2 ± 2.10</td>
<td>-</td>
</tr>
<tr>
<td>Shallow ploughing (.30 m)</td>
<td>.45 ± .02</td>
<td>.45</td>
<td>47.9 ± 2.40</td>
</tr>
<tr>
<td>Deep ploughing (.45 m)</td>
<td>.32 ± .01</td>
<td>-</td>
<td>70.0 ± 2.77</td>
</tr>
<tr>
<td>Minimum tillage (.10 m)</td>
<td>1.97 ± .23</td>
<td>+616</td>
<td>11.7 ± 1.90</td>
</tr>
</tbody>
</table>
TABLE 3 - Crop: barley; previous crop: winter wheat.
Six year means ± standard error.

<table>
<thead>
<tr>
<th>Tillage methods.</th>
<th>Effective field-work capacity (ha/h)</th>
<th>Fuel consumption (kg/ha)</th>
<th>Yield (t/ha) (standard moisture)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deep ploughing (.45 m)</td>
<td>0.27 ± 0.01</td>
<td>78.9 ± 2.80</td>
<td>5.17 ± 0.14</td>
</tr>
<tr>
<td>Shallow ploughing (.30 m)</td>
<td>0.38 ± 0.02 +41</td>
<td>61.6 ± 1.59</td>
<td>5.11 ± 0.15 -1.2</td>
</tr>
<tr>
<td>Deep ploughing (.45 m)</td>
<td>0.27 ± 0.01</td>
<td>78.9 ± 2.80</td>
<td>5.17 ± 0.14</td>
</tr>
<tr>
<td>Chiseling (.30 m)</td>
<td>0.69 ± 0.06 +490</td>
<td>13.1 ± 1.76</td>
<td>4.68 ± 0.14 -9.5</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Tillage methods.</th>
<th>Effective field-work capacity (ha/h)</th>
<th>Fuel consumption (kg/ha)</th>
<th>Yield (t/ha) (standard moisture)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deep ploughing (.55 m)</td>
<td>0.25 ± 0.01</td>
<td>84.6 ± 2.80</td>
<td>2.39 ± 0.09</td>
</tr>
<tr>
<td>Shallow ploughing (.30 m)</td>
<td>0.43 ± 0.02 +72</td>
<td>61.8 ± 1.44</td>
<td>2.45 ± 0.10 +1.7</td>
</tr>
<tr>
<td>Deep ploughing (.55 m)</td>
<td>0.25 ± 0.01</td>
<td>84.6 ± 2.80</td>
<td>2.39 ± 0.09</td>
</tr>
<tr>
<td>Subsoiler (.55 m) + Shallow ploughing (.30 m)</td>
<td>0.31 ± 0.01 +24</td>
<td>68.8 ± 1.92</td>
<td>2.38 ± 0.11 -2.1</td>
</tr>
</tbody>
</table>

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

Fig. 8 - Proctor's compactability test.

Fig. 9 - Proctor's compactability test.

CONCLUSIONS

This study demonstrates 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 CRUENTUS)

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2National Horticulture Research Institute, Ibadan (Nigeria)

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 à 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 - 25 cm depth) followed by a single pass of the harrow. The ridged seedbed (RD) was ridged to a height of 20 - 25 cm while the raised (RB) was bedded to a height of 10 - 15 cm. 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 kg ha⁻¹ in two rows in plots 2 m x 2 m spaced 1 m 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 kg ha⁻¹ and P = 0, 30, 60 kg ha⁻¹) were applied in-between the rows in two equal instalments at 4 and 8 weeks after planting (WAP). Potassium (K = 22.5 kg ha⁻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 5.0 cm. 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) fortnightly. 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 (PDM). RD and RB increased seed weight significantly. Seed weight increased as N increased from 0 to 60 kg ha⁻¹ and P from 0 to 30 kg ha⁻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 1300 h respectively; while heat flux is symmetrical about 1200 h 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 occurred 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.

REFERENCES


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

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Fertilizer Rate</th>
<th>Plant Height (m)</th>
<th>Root Length (cm)</th>
<th>Lodging (%)</th>
<th>Dry Seed Matter Weight (%)</th>
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</tr>
</tbody>
</table>

Table II: Heat Flux (Wm⁻²) Changes During a Day in the Growth and Development of *Amaranthus cruentus* L.

<table>
<thead>
<tr>
<th>Time</th>
<th>Ridge Raised Bed</th>
<th>Flat Bed</th>
</tr>
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<tbody>
<tr>
<td>0900 hrs</td>
<td>+1192</td>
<td>+1258</td>
</tr>
<tr>
<td>1200 hrs</td>
<td>-435</td>
<td>+375</td>
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<tr>
<td>1500 hrs</td>
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<td>-995</td>
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<tr>
<td>Total</td>
<td>-203</td>
<td>+638</td>
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</tbody>
</table>
Fig 1. Net hemispherical radiation (□-□) ground conduction for ridge (X-X) raised bed (○-○) and flat bed (△-△) and absolute soil heat flux.
DIFFERENTIAL PERFORMANCE OF CASSAVA (MANIHOT EXCULENTA CRANZ) PLANTED ON THE RIDGE, FLAT, FURROW AND MOUND

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Ogun State University, P.M.B. 2002, Ago-Iwoye, Nigeria

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°30′N, 7°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, 6044 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 siltv soil, mechanical impedance to root/tuber penetration seems not to constitute a deterrent 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.

REFERENCES


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

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Mechatanical Analysis (%)</th>
<th>Soil Colour</th>
<th>Moisture retention %</th>
<th>Org. C (%)</th>
<th>CEC (me/100g)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sand</td>
<td>Silt</td>
<td>Clay</td>
<td>Dry</td>
<td>Wet</td>
</tr>
<tr>
<td>0-15</td>
<td>24.3</td>
<td>70.1</td>
<td>5.6</td>
<td>5YR4/3</td>
<td>2.5YR2/4</td>
</tr>
<tr>
<td>15-30</td>
<td>13.3</td>
<td>67.1</td>
<td>19.6</td>
<td>2.5YR3/6</td>
<td>2.5YR3/4</td>
</tr>
<tr>
<td>30-45</td>
<td>9.3</td>
<td>67.1</td>
<td>23.6</td>
<td>2.5YR3/6</td>
<td>2.5YR3/4</td>
</tr>
</tbody>
</table>

Table 2. Effect of tillage on yield and yield components

<table>
<thead>
<tr>
<th>Tillage</th>
<th>% Plant survival</th>
<th>Tuber number</th>
<th>Tuber Wt ton/ha</th>
<th>Average tuber length</th>
<th>Average wt per tuber</th>
<th>Tuber number per plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mound</td>
<td>58.6</td>
<td>19218.8</td>
<td>9.94</td>
<td>36.4</td>
<td>517</td>
<td>3.29</td>
</tr>
<tr>
<td>Ridge</td>
<td>40.6</td>
<td>18862.5</td>
<td>8.59</td>
<td>35.0</td>
<td>456</td>
<td>4.79</td>
</tr>
<tr>
<td>Furrow</td>
<td>40.0</td>
<td>18893.8</td>
<td>10.10</td>
<td>35.2</td>
<td>535</td>
<td>4.80</td>
</tr>
<tr>
<td>Flat</td>
<td>25.8</td>
<td>10925.0</td>
<td>5.52</td>
<td>34.2</td>
<td>505</td>
<td>4.32</td>
</tr>
<tr>
<td>SE</td>
<td>5.73</td>
<td>2256.3</td>
<td>0.99</td>
<td>1.2</td>
<td>25.6</td>
<td>0.48</td>
</tr>
</tbody>
</table>
REDUCED TILLAGE AND STRAW INCORPORATION FOR WINTER BARLEY

B.C. BALL, D.C. BICKERTON and E.A.G. ROBERTSON

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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.

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

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 I). 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.](image)

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.](image)
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.

![Graph](image)

**Fig. 3.** Dry bulk density in July 1987.

![Graph](image)

**Fig. 4.** Soil temperature in straw layers in the ten day period after sowing.
Soil temperatures were monitored constantly throughout the last season. Temperatures at depths corresponding to most of the straw for three contrasting treatments are given in Fig 4.

Results of measurements of denitrification and straw breakdown rate made in the first season are given by Robertson and Ball (1987).

DISCUSSION

Shallow incorporation of straw tended to make the crop yellow after sowing and susceptible to subsequent winter kill. Yellowing was associated with waterlogging and poor drainage. These effects were most marked in the second winter, the wettest and coldest of the three winters, when the crop suffered sufficient winter kill for substantial reductions in crop yield to occur. Of the reduced tillage techniques, rotavation before seed broadcasting is as adequate a method of incorporation as deeper disc plus tine cultivation and drilling.

Straw breakdown rate is influenced strongly by soil temperature. The average soil temperature and the accumulated day degrees above the average were both greater where straw was incorporated nearer the surface than by conventional ploughing. This may have accounted for the greater rate of breakdown of straw at shallower depths (Robertson and Ball, 1987). In addition, at a given depth in the soil profile, the average and the maximum temperatures were greater where straw incorporation was shallow than where it was deep. This was caused by the greater heat storage in the more compact soil below incorporation depth in the shallow than in the deep incorporation treatments.

Increases in organic matter content in the reduced tillage treatments, though relatively small, were reflected in increases in the stability of soil aggregates to wet sieving, also measured after three years of treatment. For example, in the top 50 mm of the rotavated incorporation treatment 64% of 2.0-2.8 mm diameter aggregates were water stable. This was 10% more than in the same layer in the stubble treatment ploughed to 200 mm. These changes, allied to increased earthworm numbers and changes in microflora indicate progressive improvement in soil structure and resistance to erosion and compaction which may make shallow incorporation better for soil conservation than deeper incorporation by ploughing.

The presence of straw plus stubble in comparison to stubble only improved drainage under ploughing as shown by the faster increase in soil water suction in the spring (data not given) and lower topsoil water contents (Fig 2.). Strips of straw buried during ploughing gave localised zones of low bulk density (Fig.3) which acted like mole channels improving drainage on the sloping site. Such improvements in drainage may be associated with improved structure.

CONCLUSIONS

1. Shallow ploughing was the most reliable method of reducing tillage for straw incorporation.

2. Shallow incorporation of straw without ploughing gave a greater likelihood of winter kill of crop and consequent yield reductions than with ploughing, though accumulation of organic matter with shallow incorporation increased aggregate stability.

3. Ploughing of straw plus stubble improved drainage in comparison to stubble only, particularly where the straw was concentrated in strips.
REFERENCES


EFFECT OF DIFFERENT METHODS OF TILLAGE ON THE GROWTH OF RICE AND SOYBEAN ON RED YELLOW PODZOLIC SOIL IN SUMATRA, INDONESIA

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ABSTRACT

Red Yellow Podzolic Soil dominates the largest part of the upland agriculture areas in Western Indonesia. The cropping patterns most adopted are upland rice during the rainy season, peanut or soybean as the second crops and cowpea or mungbean as the third crop. Uneven rainfall may cause the second and the third crop to suffer from drought. Research was conducted to investigate the effect of tillage on the growth and yield of food crops. Result showed that deep tillage improved growth, especially root penetration and yield during the dry season.

INTRODUCTION

The Red Yellow Podzolic Soils have been officially recognized in the Indonesian soil classification by Dudal and Soepraptohardjo since 1957, as cited by Buurman (1980). The unit is based on the American concept of the great soil group. However, since the Red Yellow Podzolic Soils in Indonesia are in intricate association with different kinds of soils of low productivity, the unit was used to cover all the unproductive red or yellow acid soils. The definition was purposely kept wide: Red Yellow Podzolic Soils are those red soils that are not Latosols and Mediterranean Soils (Rapat Kerja Perluasan Areal Pertanian, 1969) and are classified as Oxisols and Ultisols in Soil Taxonomy (Buurman, 1980). This soil is formed from different kinds of acidic parent materials such as volcanic tuffs, granites, shales, sandstones or some intermediate sources such as andesitic tuff (Buurman, 1980). Red Yellow Podzolic Soils cover a large part of the Indonesia land surface; approximately 30% or 0.51 million square km (Driessen and Soepraptohardjo, 1974).

The climate of Sitiung (having Red Yellow Podzolic Soils) is humid tropical with rainfall ranging between 2500 to 3000 mm per year. Mean minimum and maximum air temperatures range from 20 to 30°C. Relative humidity is generally high (75%) and average sunshine hours range from 4.3 to 6.1 hours per day (SRI, 1979). In many weathered acid soils (Bouldin, 1979), as cited by Haynes (1984), subsoil acidity limits crop yields even if the plough layer is adequately limed. Arya et al (1987), have mentioned that apart from the effects attributable to soil fertility, acidity may lead to water stress which in turn effects crop yield. The observed effects have been attributed to restricted root growth. Root proliferation may be curtailed in subsoil horizons of such soils due to A1 toxicity, with the result that subsoil moisture is unavailable to the crops (Haynes, 1984). Several studies have demonstrated that it is possible to modify soil pH and exchangeable Ca in the subsoil for 2 to 5 years through leaching of surface-applied lime (Mahillum et al., 1970; Bailey et al., 1976 and Bouldin, 1979) as cited by Haynes (1984).

The quantitative information on the inter-relationship of root growth, crop performance and soil factors remain unavailable for Red Yellow Podzolic Soil at Sitiung. Sukarami Research Institute for Food Crops (SARIF) has recently begun field investigations on soil tillage methods in relation to root growth and their relationship to soil and plant factors. The objective is to determine the effect of tillage on root
penetration, subsoil chemical changes and consequently on crop yield in Red Yellow Podzolic Soil at Sitiung. Preliminary results are reported in this paper.

MATERIALS AND METHODS

The site chosen for this experiment had not produced a crop nor had it been cultivated for at least 5 years prior to initiating the experiment. The experiment was laid out during the rainy season of 1986/1987. The first crop was upland rice (Danau Bawah Variety). It was followed by soybean (Wilis Variety). The treatment consisted of two factors: first tillage methods i.e.: Conventional (whole plot was hand hoed 10-15 cm deep); row tillage 15 cm deep; row tillage 30 cm deep and row tillage 45 cm deep, second two lime rates i.e.: 0 and 2 tons/ha were applied at surface and incorporated. The experiment was arranged in a Factorial Randomized Design, with three replications. The plot size was 4 x 5 m. Conventional tillage was performed by hoeing the whole plot using a hoe. Row tillage was done by hoeing at 15 cm depth. Row tillage to 30 cm was done by hoeing up to 15 cm depth, the soil was dug up and put aside. The subsoil (15 to 30 cm depth) was then cultivated. The topsoil (0-15 cm depth) was returned on top. The row tillage at 45 cm depth was done by digging up 0 to 15 cm layer, put on one side of the row, the 15 to 30 cm depth was dug up and put to the other side. The third layer (30-45 cm depth) was cultivated properly. The two layers were returned. Lime was applied at the rate of 0 and 2 t/ha broadcast on the soil surface and incorporated. Root penetration and plant height were observed during full flowering period for upland rice and soybean. Yield was measured after harvest. Soil samples were analyzed for Ca, K and Al availability in the central laboratory of SARIF.

RESULTS AND DISCUSSION

Plant height

Table 1 depicts the data on plant height of upland rice and soybean. The plant height of upland rice was not affected by the method of tillage and liming. This proves that upland rice is slightly tolerant to high Al conditions. In the case of soybean liming increased the plant height for each tillage method (Table 1).

Table 1. Plant height of upland rice and soybean as effected by four tillage methods and two lime rates at Sitiung 1987.

<table>
<thead>
<tr>
<th>Crop</th>
<th>T+L+</th>
<th>C</th>
<th>15 cm</th>
<th>30 cm</th>
<th>45 cm</th>
<th>average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upland rice</td>
<td>69.0</td>
<td>86.2</td>
<td>84.5</td>
<td>86.3</td>
<td>80.2</td>
<td>89.0</td>
</tr>
<tr>
<td>Soybean</td>
<td>36.8</td>
<td>46.7</td>
<td>41.0</td>
<td>47.7</td>
<td>36.3</td>
<td>44.3</td>
</tr>
</tbody>
</table>

+Tillage methods (T) Conv, 15 cm, 30 cm and 45 cm
Lime rates (L) 0, 2 tons/ha

Root penetration

Root penetration of upland rice, is affected by tillage methods and lime rates, is presented in Table 2. With conventional tillage, lime application did not affect root penetration of upland rice, but there was significant effect on soybean. Root penetration
increased with depth of tillage as it increased from 15 to 30 cm. Deeper tillage at 45 cm showed less effect. Lime had a clear effect on soybean root penetration.

Table 2. Root penetration of upland rice and soybean as effected by four tillage methods and two lime rates at Sitiung 1987.

<table>
<thead>
<tr>
<th>Crop</th>
<th>T+ L+</th>
<th>15 cm</th>
<th>30 cm</th>
<th>45 cm</th>
<th>average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upland rice</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Soybean</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

4Tillage methods (T) Conv, 15 cm, 30 cm and 45 cm
Lime rates (L) 0, 2 tons/ha

Yield

Grain yield of upland rice, could not be recorded due to early attack by Helminthosporium and Cercospora fungi. Soybean grain yield was much increased by depth of tillage from 15 to 45 cm, the yield was increased from 0.67 to 0.99 t/ha (48%) and from 0.70 to 1.18 t/ha or 69% for non-limed and limed plots, respectively. The effect of the depth of tillage was more significant when compared to effect of lime on soybean.

Soil chemical analysis

Table 4 shows the distribution of exchangeable calcium, potassium and aluminum with depth as affected by tillage methods and lime treatment. The most important point to note is that the effect of lime on exchangeable calcium, potassium and aluminum can be observed only in the surface soil between 0 to 10 cm layer. Below the 10 cm layer, the effect did not follow a discernible trend. Similar results have been obtained in a number of other studies (Adams and Hathcock, 1984, Richigl et al., 1985; Doss et al., 1979; Longnecher and Sprague, 1940 and Haynes, 1984).

Table 3. Yield of upland rice and soybean (t/ha) as effected by four tillage methods and two lime rates at Sitiung 1987.

<table>
<thead>
<tr>
<th>Crop</th>
<th>T+ L+</th>
<th>15 cm</th>
<th>30 cm</th>
<th>45 cm</th>
<th>average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upland rice</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Soybean</td>
<td>0.58</td>
<td>0.79</td>
<td>0.67</td>
<td>0.70</td>
<td>0.93</td>
</tr>
</tbody>
</table>

4Tillage methods (T) Conv, 15 cm, 30 cm and 45 cm
Lime rates (L) 0, 2 tons/ha
Table 4. Distribution of exchangeable calcium, potassium and aluminum (meq/100 g) observed 6 months after the application as affected by four tillage methods and two lime rates at Sitiung 1987.

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>T†</th>
<th>L‡</th>
<th>Conventional row 15 cm</th>
<th>0</th>
<th>2</th>
<th>row 30 cm</th>
<th>0</th>
<th>2</th>
<th>row 45 cm</th>
<th>0</th>
<th>2</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>calcium</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-10</td>
<td>0.91</td>
<td>1.47</td>
<td>1.05</td>
<td>2.12</td>
<td>1.00</td>
<td>1.58</td>
<td>1.00</td>
<td>1.68</td>
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</tr>
<tr>
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<td>0.96</td>
<td>0.71</td>
<td>1.55</td>
<td>1.65</td>
<td>1.15</td>
<td></td>
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<tr>
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<td>0.78</td>
<td>0.85</td>
<td>0.69</td>
<td>0.58</td>
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<td>0.79</td>
<td>1.06</td>
<td></td>
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</tr>
<tr>
<td>40-60</td>
<td>0.45</td>
<td>0.63</td>
<td>0.59</td>
<td>0.63</td>
<td>0.49</td>
<td>0.53</td>
<td>0.45</td>
<td>1.72</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
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</tr>
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<td>0.18</td>
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</tr>
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<td>0.09</td>
<td>0.10</td>
<td>0.11</td>
<td>0.14</td>
<td>0.13</td>
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<td>0.12</td>
<td>0.13</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20-40</td>
<td>0.07</td>
<td>0.08</td>
<td>0.08</td>
<td>0.09</td>
<td>0.09</td>
<td>0.07</td>
<td>0.06</td>
<td>0.07</td>
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</tr>
<tr>
<td>40-60</td>
<td>0.06</td>
<td>0.07</td>
<td>0.05</td>
<td>0.06</td>
<td>0.06</td>
<td>0.05</td>
<td>0.05</td>
<td>0.07</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>aluminum</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-10</td>
<td>2.20</td>
<td>1.71</td>
<td>1.17</td>
<td>1.07</td>
<td>2.08</td>
<td>0.88</td>
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<td>1.43</td>
<td></td>
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<tr>
<td>10-20</td>
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<td>2.20</td>
<td>1.53</td>
<td>1.71</td>
<td>1.77</td>
<td>1.36</td>
<td>1.28</td>
<td>1.53</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20-40</td>
<td>0.98</td>
<td>1.21</td>
<td>1.02</td>
<td>1.03</td>
<td>1.22</td>
<td>0.67</td>
<td>0.79</td>
<td>1.29</td>
<td></td>
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</tr>
<tr>
<td>40-60</td>
<td>0.61</td>
<td>0.55</td>
<td>0.61</td>
<td>0.49</td>
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<td>0.37</td>
<td>0.73</td>
<td>0.68</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

†Tillage methods (T): Conv, 15 cm, 30 cm and 45 cm
‡Lime rates (L): 0, 2 tons/ha

CONCLUSIONS

1. Root penetration of soybean in red yellow podzolic soils is inhibited due to aluminum. But deep tillage can negate the effect of aluminum toxicity.

2. The effect of liming of acid soils, on the availability of Ca, K and aluminum are confined to the surface soil layer only.

REFERENCES


RELATIONS BETWEEN AGRONOMICAL FACTORS AND SOIL CONDITION IN MODERN TILLAGE SYSTEMS

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ABSTRACT

It is characteristic of Hungarian farming to apply new and traditional cultivation methods together. New practices, such as soil conservation and cultivation without ploughing have been adopted, which guarantee the same level of yield on a given field. It is also essential that the tillage cost should be reduced.

It is agronomically necessary to use those kinds of machinery and machine combinations which make it possible to reduce clod formation, eliminate the harmful packing of soil and avoid making the earth dusty.

At present, no-till farming is very uncommon in Hungary. Soil conserving cultivation focuses on the preservation of soil structure and is closely related to the sequence of plants grown.

Cultivation practice does not favour the use of stubble to protect the soil. Incertain habitats the peculiarities of the site makes shallow discing more of a risk.

THEORY

The importance of cultivation can be evaluated by the size of the cultivated area, the time, energy and cost it requires, the effect it has on the yields of crops and recently by the effects it has on the soil structure.

The total amount of ploughland in Hungary is 4.705 million ha. Fifty-five per cent of all soils are very heavy and can hardly be tilled, 25 per cent is heavy, 35 per cent is medium light and 15 per cent is light. The Arany's number of soil heaviness i.e. the number of grammes of water added to 100 grammes of air-dry soil that just liquefies it/ influences the cultivability and the time and energy needed to produce optimum soil conditions.

The similarities between Hungarian and foreign cultivation techniques and practice, the favourable and harmful effects of the modern machinery applied, can be determined by the need for soil conservation and water preservation.
The differences are the following:

1/ The aspects of cultivation, the speed of alterations as the necessity for alteration is recognized.
2/ The difference between the range of machinery for sale and the range of machinery available on average farms.
3/ The speed with which procedures and methods connected with new implements gain acceptance.
4/ The size of fields to be tilled on each farm each season.
5/ The possibilities of soil conservation.
6/ The possibilities of soil conservation.
7/ Economic and environmental differences.
8/ Constraints. The recognition, judgement of and elimination of risk.

The theoretical and practical tasks of cultivation below result from the factors listed above.

1/ The moisture content and compactness of soils, the implements and methods used.
2/ The cultivation carried out before primary cultivation and its effect on the quality of land preparations, the total number of tillage passes.
3/ The different ways of incorporating crop residues, and cultivation without ploughing.
4/ The relationship between perspective implements, methods and soil protection.

The factors and tasks listed are subject to the agronomic and mechanizational research being done at present and in the near future. Our research is related to these topics. Our results summarize approximately 12 years of research. The estimations were done with the equations:

\[ Y' = a + b_1x_1 + b_2x_2 \]
\[ Y' = a + b_1x_1 + b_2x_2 + b_3x_3 \]

using three independent variables.

RESULTS AND DISCUSSION

1. The moisture content and compactness of soils and the implements and methods used.

We examined the clod forming effect of certain tilling methods such as ploughing, scufflering, application of discs and heavy cultivator on sandy loam, loam, clay loam, clay and heavy clay soils with 6-28 mass percentage moisture content. It is known that when using different implements on soil with the same moisture content and compactness, the clod formation is also different. However the size of clods and the proportions of clod fractions can be affected. The influence of the two independent variables /the moisture content of the soil has a 3 to 4 times stronger effect on clod formation than the total porosity has when plough, disc, medium deep scuffler combined with disc and Conser Tills are used.
The compactness of soil has a greater effect when a medium deep scuffler with chisel is used. Research evidence indicates reliably \( p = 0.1 \% \) that certain tilling should be used on soils with different moisture content.

To judge the factors influencing clod formation it is better to use three independent variables. These are the moisture content of soil, the compactness of soil, measured by bulk capacity in two, the upper 0-10 cm and three, the lower 28-32 cm layers of soil.

There is considerable evidence that certain axioms apply to each type of soil. Clod formation on a land ploughed 30 cm deep is mainly determined by the compactness of the upper 0-10 cm layer. If the physical condition of this layer are favourable, that is 1,40-1,48 g.cm\(^{-3}\) value can be used to describe it, the clod formation can be reduced even if the soil is dry. The other two factors which have the same effect on the amount of clods on a land ploughed 30 cm deep are the moisture content of the soil and the compactness of the lower layer /28-32 cm deep/. It is very important to maintain the appropriate soil conditions. This can be proved mathematically.

The amount of clods made by scufflering the soil 40-45 cm deep is primarily influenced by the moisture content of the soil, secondly the compactness of the layer between 28-32 cm which is the usual depth of plowpan.

The clod forming effect of plowpan can also be definitely proven when the soil is scufflered 60-65 cm deep. When the soil is scarified under dry conditions the clod formation is mainly determined by the compactness of the upper 0-10 cm soil layer. The results show that previous crops harvested long before the main crop is sown, restore the favourable soil conditions /1,40-1,48 g.cm\(^{-3}\) bulk densities/.

2. The interventions carried out before primary cultivation and their effect on the quality of the land preparation the total number of tillage passes. The results listed in point 1 justify the influence of three factors on the quality of primary cultivation preceding the establishment of seedbed.

The first element of classical tillage practice is stubble cleaning. In dry years the unfavourable cloddishness can be reduced if the stubble cleaning is carried out correctly. In this way the 5-6 passes which are a common number for sowing winter wheat on pea can be cut down to 4. The recommended implement for primary cultivation is a medium deep scuffler combined with disc or heavy cultivator. When winter wheat is sown on winter wheat similar number of turns are satisfactory if the primary cultivation is done by medium deep wing type scuffler.
3. Crop residues and the omittability of turning.

The crop residues /the amount and chopability/ of the previous crop greatly influence the method /tillage with or without turning/ and implements of primary cultivation. It must be emphasized that the stubble cleaning should be carried out right after cropping but there is no agronomic reason to do it deeper than 10-12 cm.

Previous practice recommended ploughing when winter wheat was sown on winter wheat, sunflower and sugar-beet. Based on our research it can be proven that the 1.40-1.48 g/cm³ bulk density of the upper soil layer which can be made by stubble cleaning or chopping stalk residues with a disc can improve the quality of primary cultivation. Quality in this sense means the predomination of mixing. Primary cultivation can be done either with a wing-type scuffler or heavy cultivator after the three crops mentioned above. Thus ploughing can be eliminated on dry soils, the cloddisliness and the number of turns, when the soil is worked down, can be reduced.

The importance of the results is emphasised by the fact that it is uncommon in Hungary, to leave crop residues on the soil surface in order to protect the soil.

4. The relationship between perspective implements, methods and soil conservation.

It is generally thought that the conservation of soil structure has priority in all types of habitat. Parallel with the avoidance of clod formation, the formation of silt can also be reduced. It is imperative to apply those machines /see figure/ on dry soils which are suitable for the moisture content in the soil. Today a wide variety of these machines are available as: 3 to 5 types of heavy cultivators, disc and scufflers. On the other hand shallow tillage with disc is recommended only on soils which are not harmfully compacted. Humid soils should be ploughed shallow since there is no opportunity to avoid this. In turn the plowpan should be burst with cultivators or scufflers the next year. Cultivators and scufflers can be prospectively used on sloping fields as well.

During the last 4-5 years the demand for reversible ploughs and ploughs connected with machines which work down the furrow has been increasing constantly because these implements can reduce the number of traffics, and thus compacting.

After a long controversy the views that cultivation should be adjusted to the habitat, the soil conditions and protection and that ploughing is not the only farming practice has gained ground.
CONCLUSIONS

1. The different land conditions encountered the 4,705 million ha of plowland in Hungary and the prevailing tillage practices need a complex application of traditional and up-to-date cultivation methods.

2. Though the soil conserving methods and direct drilling which work well abroad, are known in Hungary only those practices spread which can assure the same or higher yields than the usual each year.

3. The peculiarities of certain fields may necessitate the elaboration of special methods suitable to only that land.

4. The conservation of soil structure carried out with modern implements requires less energy. In addition there is a revival of traditional farming practices.

5. It is firstly essential to choose the appropriate cultivation method suitable for a certain moisture content in order to reduce the number of passes and conserve the soil structure.

6/ The clod forming effects of any primary cultivation methods can be reduced if
a/ the tillage method harmonizes with the moisture content
b/ the stuble cleaning is readily done and favourable physical conditions are established in the upper 0-20 cm layer of soil.
   c/ the favourable physical conditions of lower soil layers are restored periodically.

7/ Crop residues on the stubble does not necessitate ploughing. If there are favourable soil conditions in the upper 0-10 cm soil layer the effectiveness of implements can be optimally increased including stirring.

8/ By utilizing the agronomic properties of a soil the number of passes in the total cultivation, herewith and the losses in moisture content, the compacting and destruction of soil structure can be reduced.
OPTIMAL SOIL MOISTURE CONTENT OF VARIOUS PRIMARY CULTIVATION OPERATIONS

Cultivation equipment and depth /cm/

- PLOUGH
  -30
  -35
- RIPPER combined
  -48
- DISC
  -20
  -35
- RIPPER combined DISC
  -38
- CONSER TILL
  -25
  -35
- RIPPER
  -45
  -45
- WING-TYPED CHISEL
  -38
- RIPPER
  -50
- RIPPER
  -60
  -50
  -45
  -66
MULTI TILLER
  -66

$X_K_A = \text{Number by Arany: The amount of water expressed in grams that has to be added to 100g of air-dried soil to make it fluent.}$

increase of clodiness

moisture content w/w% 4 8 12 16 20 24 28

increase of soil puddling

$K_A^X$
CHOOSING TILLAGE IMPLEMENTS
A PRACTICAL GUIDE FOR FARMERS

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ABSTRACT

A wide range of data and papers from Agricultural Research, Development and Manufacturers has been used by the authors to develop a practical guide for choosing implements for cultivation. This guide includes a classification of implements, charts for selecting the right one and descriptive tables for each type of equipment. It helps to select the type of equipment adapted to the soil and crop found on a given farm.

Actually the same type of report is being done for seed drills. Other studies should lead to refining a whole farm simulation model involving equipment, organisation and economic results.

INTRODUCTION

The farmers decision concerning cultivation and seeding can be classed in 3 categories:
- the choice of cultural practices for soil preparation,
- the choice of tillage and seeding implements capable of carrying out the programme of cultivation,
- the application of these different tools at one or several periods in the year.

These decisions imply a good understanding of all aspects of these implements (principle of operation, the probable effects on the soil in respect of adjustments, working rate, investment, manufacturer, ...).

Until now, knowledge of cultivation equipment has been scattered about in different publications and part of this information has been distributed to a small number of specialists.

That is why I.T.C.F. has done a synthesis (1) of this information available in France on equipment for soil preparation. This work has resulted in a practical guide designed:
- to compare different types of implements,
- to become familiar with the characteristics of each category of equipment,
- to appraise what is being offered by manufacturers.

MATERIALS AND METHODS

Documents used

They come from Research, Development or Manufacturers. The recent studies of French Research Organisations based on soil cultivation problems were used for this document.
Specially those from the Institut National Agronomique PARIS-GRIGNON (SEBILLOTTE and MANICHON) and from the Centre National du Machinisme Agricole, du Génie Rural et des Eaux et Forêts (C.E.M.A.G.R.E.F. - DALLEINE and BILLOT).

We have also assembled a large number of observations on the behaviour of these implements observed in field trials of technical institutes such as I.T.C.F. or Regional Advisory Services.

(1) The brochure "CHOIX DES OUTILS DE TRAVAIL DU SOL" is available in french at I.T.C.F. PARIS.

ADAS is preparing an English adaptation and translation.
Finally a lot of documents were given to us by the technical services of the manufacturers of equipment for soil preparation: mechanical characteristics, operating conditions, prices etc...

**Procedure used**

The procedure used for synthesis of the assembled data included 3 stages:

- The first was to define a classification table of the principal types of tillage implements. This is achieved by comparison tables between types of implements and manufacturers trade marks.
- The second stage concerned the choice of equipment by function of 3 criteria:
  - the mechanical behaviour of the soil, the tillage operation being considered and the desired effects.
  - For the third stage, we have given a detailed description of the mechanical, agricultural and commercial characteristics of each type of machine.

**RESULTS**

**Classification of implements**

Five main classes of agricultural implements were established: tine implements, mouldboard implements, disc implements, P.T.O. implements, and miscellaneous. Inside each class, several types have been classed according to the height under the frame, the number of working "tines" per meter, etc...

Table 1 presents 9 types of tine implements.

**TABLE I**

Classification of tine implements

<table>
<thead>
<tr>
<th></th>
<th>HEIGHT UNDER FRAME</th>
<th>N* OF WORKING &quot;TINES&quot; PER METER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy sub-soiler</td>
<td>75-110 cm</td>
<td>1-2</td>
</tr>
<tr>
<td>Light sub-soiler</td>
<td>60- 75 cm</td>
<td>2-3</td>
</tr>
<tr>
<td>Chisel plough</td>
<td>60- 75 cm</td>
<td>3-4</td>
</tr>
<tr>
<td>Spring tine cultivator</td>
<td>60- 75 cm</td>
<td>4-5</td>
</tr>
<tr>
<td>Light tine cultivator</td>
<td>45- 60 cm</td>
<td>4-7</td>
</tr>
<tr>
<td>Spring cultivator</td>
<td>30- 45 cm</td>
<td>7-12</td>
</tr>
<tr>
<td>Spike harrow</td>
<td>20- 30 cm</td>
<td>12-19</td>
</tr>
<tr>
<td>Flexible tine harrow</td>
<td>15- 25 cm</td>
<td>15-30</td>
</tr>
</tbody>
</table>

**Choice of type implements**

The first choice depends upon the soil type (table II). Two criteria are taken into consideration:

- Likely physical behavior of the soil related to climate and soil cultivation. Four main soil types have been used: sandy, silty, loamy, clayey. Field observations make it possible to classify a particular soil in one of these types (easiness of crumbling in summer, sticky soil in autumn or in spring, crusting at the end of winter and in spring).
- Usual soil consistency at the time of the tillage operation is assessed, by hand, just before soil cultivation, at four levels: hard, crumbly, semi-plastic, plastic.
TABLE II

A selection of different types of implements for soil preparation according to soil consistency (physical behaviour of the soil: loamy).

<table>
<thead>
<tr>
<th>TYPE OF IMPLEMENT</th>
<th>CONSISTENCY AT THE TIME OF SOIL CULTIVATION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HARD</td>
</tr>
<tr>
<td>Rotary tiller with horizontal shafts</td>
<td>not advised</td>
</tr>
<tr>
<td>Circular spike harrow</td>
<td>possible</td>
</tr>
<tr>
<td>Power harrow</td>
<td>possible</td>
</tr>
<tr>
<td>Spring cultivator</td>
<td>possible</td>
</tr>
<tr>
<td>Spike harrow</td>
<td>possible</td>
</tr>
<tr>
<td>Flexible tine harrow</td>
<td>possible</td>
</tr>
</tbody>
</table>

The second choice between different implements depends upon the type of soil cultivation under consideration.

Nine soil cultivation techniques have been defined:
- sub soiling – ploughing – ploughless cultivation – shallow cultivation
- stubble cultivation–deep or shallow secondary cultivation after ploughing – seed bed preparation – soil rolling (table III).

TABLE III

Adaptation of different types of implements to three techniques

<table>
<thead>
<tr>
<th>TYPE OF IMPLEMENT</th>
<th>DEEP SECONDARY CULTIVATION</th>
<th>SEED BED PREPARATION</th>
<th>STUBBLE CULTIVATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotary cultivator</td>
<td>possible</td>
<td>well</td>
<td>well</td>
</tr>
<tr>
<td>Circular spike harrow</td>
<td>possible</td>
<td>suited</td>
<td>suited</td>
</tr>
<tr>
<td>Reciprocating power harrow</td>
<td>possible</td>
<td>suited</td>
<td>not advised</td>
</tr>
<tr>
<td>Spring tine cultivator</td>
<td>not advised</td>
<td>suited</td>
<td>not advised</td>
</tr>
<tr>
<td>Spike harrow</td>
<td>not advised</td>
<td>suited</td>
<td>not advised</td>
</tr>
<tr>
<td>Flexible tine harrow</td>
<td>not advised</td>
<td>suited</td>
<td>unusable</td>
</tr>
</tbody>
</table>

Considering what we hope to obtain from tillage operations, we can make a more relevant choice for our implements for soil preparation (table IV).
Nine different final effects on soil are taken into consideration: breaking the plough pan, soil loosening, burial of crop residues, soil stirring, land smoothing, creating uneven soil surface, sorting out clods and fine soil, crumbling, soil rolling.

TABLE IV

Example of a choice of implement for preparation of seed bed according to the effect required.

<table>
<thead>
<tr>
<th>TYPE OF IMPLEMENT</th>
<th>SORTING OUT CLODS/FINE SOIL</th>
<th>Dia. MAIN HARD CLODS FROM</th>
<th>FROM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5-10 cm</td>
<td>3-5 cm</td>
<td>TO &lt; 3 cm</td>
</tr>
<tr>
<td>Rotary cultivator</td>
<td>possible (according to adjustments)</td>
<td>well</td>
<td>well</td>
</tr>
<tr>
<td>Circular spike harrow</td>
<td>not</td>
<td>well</td>
<td>well</td>
</tr>
<tr>
<td>Reciprocating power harrow</td>
<td>not</td>
<td>suited</td>
<td>suited</td>
</tr>
<tr>
<td>Spring tine cultivator</td>
<td>possible</td>
<td>suited</td>
<td>possible</td>
</tr>
<tr>
<td>Spike harrow</td>
<td>well</td>
<td>advised</td>
<td>advised</td>
</tr>
<tr>
<td>Flexible tine harrow</td>
<td>well</td>
<td>not</td>
<td>not</td>
</tr>
</tbody>
</table>

Characteristics of each type of implement

First, this characterization contains a detailed description of implements belonging to this category. The following elements are examined successively:
- general design,
- working parts: plough coulters, ploughshares, mouldboards, tines, discs, blades, spades, skim coulters...
- functional components necessary for a satisfactory results (for example a roller packer on a power harrow),
- optional equipment available for certain uses (example: rear P.T.O. on a power harrow for a pneumatic drill.

The second part concerns the possibilities and limits of the equipment under consideration. The first figure explains how the implement works on the soil (Figure 1).
Free roller

Accumulation of clods in front of the first row of tines.

Dynamic action between clods and tines (if consistency is crumbly)

Smearing if soil consistency is semi-plastic.

Shaking and packing of soil structure due to vibrations under the tines.

Figure 1: Effect of reciprocating power harrow on a ploughed soil.

It is completed by instructions for adjustments and their effects on the quality of the final work: depth and regularity, crumbling, burial of crop residues, levelling...

This part finishes with examples of soil profiles created by this type of implement (Figure 2) and a table to assess the limit of use of these implements considering the physical behaviour and consistency of the soil.

The third part gives information about the following aspects:
- working rate (h.ha⁻¹),
- fuel consumption (l.ha⁻¹) and the horse power necessary (h.p.m⁻¹) or h.p. per body,
- the price list of new equipment,
- the complete directory of commercially available implements by type with their characteristics (trade mark, size...).

Figure 2: Example of a soil profile left by a reciprocating power harrow working on a ploughed soil.
To give value to this work of synthesis on the implements of tillage, it is necessary before hand to examine the properties of the soils present at the farm and to have a good understanding of crop rotations and cultural practices. In this case, it is easy to determine which types of implements are the best adapted to the physical soil conditions at the farm. The only exception is for stony soils for which this publication gives no indications.

The index cards describing the equipment enable a selection of the working parts and components which suits the soils of the farm.

The informations given by the brochure is not sufficient to evaluate the consequences that the choice of implements can have on the management and economic results of the farm. This kind of evaluation requires a comprehensive analysis with costed benefits of the effects on soil structure and crop growth etc.

CONCLUSIONS

The gathering and analysis of results and various documents (from Research, Development and Manufactures) has enabled us to produce for farmers and their advisors a practical guide effective for choosing the types of tillage implements best suited to their soils and crops.

The same methods could be used for other equipments such as drills.

Such an approach has the advantage of readily presenting available data and shows the studies which should be developed concerning relationships between implements, soil type, plant and farm in order to optimise the choice of implements.

REFERENCES

DEVELOPMENT OF DIRECT DRILLING SYSTEMS UNDER PERHUMID SOIL ENVIRONMENTS IN ATLANTIC CANADA

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Agriculture Canada, Research Station, Charlottetown, Prince Edward Island C1A 7M8 (Canada)

ABSTRACT

Soil and climate interactions can influence the soil tillage requirement and the development of tillage systems. This study provides an overview of the adaption of direct drilling systems on sandy loam soils under the cool boreal, humid to perhumid soil climate of Atlantic Canada, where the growing season is relatively short (May to October). Direct drilling overcame the constraints of limited field workdays for seeding of spring cereals, due to wet soil conditions in early May, or the integration of planting date with optimum soil temperatures for silage corn (*Zea mays* L.). However, the advantage of timeliness can be offset due to a combination of reduced macroporosity at the soil surface and increased percentage of water-filled pore space. The presence of standing crop residue, however, in pasture renovation studies, allowed sequential direct drilling to occur with no adverse effect on soil structure.

INTRODUCTION

The interplay between soil and climatic factors is an important consideration for the development of optimum tillage systems, especially direct drilling. In general, the assessment of soil suitability for direct drilling, by determination of soil behavioural properties and susceptibility to compaction, must also be cognizant of the prevailing soil climatic regime (Carter, 1987a).

In the cool boreal, humid to perhumid soil climate of Atlantic Canada, several significant constraints, such as high rainfall and low soil temperature at seeding time, influence tillage requirements. In addition, the susceptibility for compaction of many soils in Atlantic Canada (Saini et al., 1984; Carter, 1987a) will also affect the choice of cultivation system. However, the potential advantage of direct drilled systems, in regard to timeliness, may allow earlier seeding and possibly offset the constraints of a short growing season.

The objective of this paper is to provide an overview of several direct drilling systems which have been successfully adapted to the soil climate of Atlantic Canada. Emphasis is placed on characterizing soil and climatic constraints for agricultural systems, and describing the soil response under specific direct drilling systems for cereals, corn, and forage.

CONSTRAINTS OF THE SOIL CLIMATE

The soil climate in Atlantic Canada is characterized by mainly cool or moderately cool boreal soil temperature classes, although some soils are classed as moderately cold cryoboreal (Agriculture Canada Expert Committee
Relatively high precipitation in the spring is a major climatic constraint for agricultural systems since wet soil conditions limit the number of field work days for both primary and secondary tillage, and seeding operations. In Prince Edward Island, due to diseases and other agronomic factors, optimum yield and quality of spring cereals is dependent on seeding in early May. Regression analysis, comparing relative yield of spring cereals with seeding date after May 1, indicated that potential yield decreases occur before substantial field work days are accumulated. A second major climatic constraint for some crops is relatively low soil temperatures in the spring. Although soil temperatures, at the 5 cm depth, may be within the optimum range for cereals in the germinating phase, they can significantly affect the planting date for corn (Zea mays L.) (White, 1977). Regression analysis comparing relative dry matter yield and the mean soil temperature at 5 cm depth showed that by the time soil temperature had increased to an optimum level, potential decreases in relative yield were probable.

Most of the soils in Atlantic Canada belong to the Podzolic and Luvisolic Order (Agriculture Canada Expert Committee on Soil Survey, 1987) and are susceptible to soil compaction. Recent studies conducted in New Brunswick and Prince Edward Island have shown that soil compactibility is related to both soil particle size and organic carbon content (Sani et al., 1984; Carter, 1987a). In general under perhumid moisture regimes, a slight degree of soil compaction may be detrimental to the maintenance of adequate soil aeration. Optimum macroporosity is required to ensure that the water-filled pore space does not exceed 60 to 70% of the total soil porosity (Carter, 1987b). In cases where direct drilling increases soil compaction at the soil surface, the combination of reduced macroporosity, compared to mouldboard ploughing, and high water-filled porosity due to moist soil conditions may adversely reduce soil aeration (Table 1).

Table 1. Effect of sequential direct drilling (DD) and mouldboard ploughing (MP) on macroporosity and water-filled pore space in a Charlottetown fine sandy loam.

<table>
<thead>
<tr>
<th>Soil depth (cm)</th>
<th>Macroporosity (% soil volume, v/v)</th>
<th>Water-filled pore space (% pore volume, v/v)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DD</td>
<td>MP</td>
</tr>
<tr>
<td>0-8</td>
<td>8.2</td>
<td>14.2*</td>
</tr>
<tr>
<td>8-16</td>
<td>6.0</td>
<td>9.6*</td>
</tr>
<tr>
<td>16-24</td>
<td>7.5</td>
<td>8.8</td>
</tr>
</tbody>
</table>

*Soil moisture at 35.0% (v/v) is close to field capacity.

Soil and climatic interactions, in regard to direct drilling, are also reflected in tillage-induced changes in soil biological properties. Direct drilling increases microbial biomass C and N at the soil surface, in comparison to mouldboard ploughed systems (Carter, 1986). Comparison of direct drilling systems showed that microbial biomass carbon, which provides an index for potential changes in soil organic carbon, increased at the soil surface (0-5 cm) in relation to the overall soil moisture conditions.
regime.

**DEVELOPMENT OF DIRECT DRILLED SYSTEMS**

**Spring cereals**

Preliminary studies conducted with spring cereals indicated that grain yields and quality tended to rank lower under direct drilling compared to other tillage systems, although yield parameters were statistically similar. Generally, the tendency for lower yields under direct drilling has been associated with increases in soil compaction and reduction in soil macroporosity (below 10% soil volume) at the soil surface (Carter, 1987b). In a series of experiments, the use of some degree of soil loosening prior to direct drilling significantly increased grain yield and quality, compared to direct drilling alone. An alternative strategy used direct drilling on a rotational basis with forages to maintain optimum soil structure conditions (Carter, 1987a). For example, direct drilling spring cereals into a red clover (*Trifolium pratense* L.) sod prevented deliterious changes in soil compaction. In addition, crop yields were similar between tillage systems, although differences in grain quality still occurred. Evidently, optimum levels of organic carbon at the soil surface, along with the presence of standing crop residue, tends to prevent the increase in soil compaction associated with sequential direct drilling systems (Carter, 1987a).

**Corn silage**

Choice of tillage system for corn is based on timeliness to allow fast establishment, as soon as soil temperature becomes optimum. Early studies compared direct planting to mouldboard ploughed systems for continuous silage corn. In general, after 2 years, yields of silage corn began to decline in comparison to mouldboard ploughed and shallow tillage systems. Yield decreases were associated with lower plant populations due to poor seed establishment and greater soil surface compaction relative to the other treatments.

A second series of experiments used direct planting on a rotational basis. In these studies, a relatively light, standard corn planter was used, which had been modified to allow adequate soil penetration and seed placement (White et al., 1986). Using a two year rotation (direct planted corn - spring barley) tended to maintain corn dry matter yield and plant populations at a similar level as a conventional tillage system. After five years, alternating direct planting and mouldboard ploughing reduced the level of soil compaction associated with continuous direct planting. Penetration resistance profiles indicated a tillage-induced compacted layer in the continuous direct planted corn treatment, compared to the continuous mouldboard ploughed corn, or direct planted corn/spring barley rotation.

In most cases, freeze-thaw forces can amerliorate traffic-induced soil compaction occurring over the 0 to 20 cm depth. Detailed studies under a four year continuous direct planted corn rotation, indicated that natural forces during the winter period did regenerate soil structure, by increasing the maximum depth to a penetration resistance of 1.5 MPa from 12 to 25 cm (Carter and White, 1986). However, subsequent planting operations increased soil compaction, tending to increase penetration resistance by 0.5 MPa down the soil profile.
Pasture renovation

In Atlantic Canada, initial pasture improvement studies concluded that renovation, resulting in greater forage yields and quality, could be accomplished without use of extensive soil cultivation. In many cases, however, pasture renovation is required on a regular basis to maintain adequate legume growth in grass dominant swards. Under these conditions, direct seeding has proved successful for regular introduction of legumes into pastures. A series of experiments assessed the performance of direct drilled alfalfa (Medicago sativa L.) and birdsfoot trefoil (Lotus corniculatus L.) into grass dominant swards (Kunelius et al., 1982). Additional studies also included direct drilled red clover (Trifolium pratense L.) and white clover (T. repens L.) (Kunelius and Campbell, 1984). Direct drilling has also been successfully used for the establishment of Italian ryegrass (Lolium multiflorum Lam) into grass swards (Kunelius et al., 1986). Italian ryegrass is not winterhardy in Atlantic Canada and needs to be reseeded on a regular basis. Direct drilling allowed the fast establishment of Italian ryegrass and reduced the risk of soil erosion, in comparison to cultivated systems.

Generally, direct drilling for renovation of pastures has not adversely affected soil structure. This is probably related to the presence of a surface mulch at the soil surface which can alleviate soil compaction by modifying the effect of applied stress. In addition, depending on the condition and density of the pasture sod, different seeders have been used to provide varying widths of cultivation within the seed row if required. A series of soil structure studies under direct drilling systems for Italian ryegrass (Carter and Kunelius, 1986; Kunelius et al., 1986), and alfalfa, red clover, and timothy indicated that soil physical conditions were maintained within the optimum range for crop growth (Carter and Kunelius, 1986).

SUMMARY AND CONCLUSIONS

Under the cool boreal, perhumid soil climate of Atlantic Canada direct drilling systems offer the advantage of timeliness and the potential to reduce soil erosion. However, the combination of soil types and soil climate present several constraints to the adoption of direct drilling practices. Comparison of soil structure on a Charlottetown fine sandy loam under direct drilling systems for spring cereals, silage corn, and pasture renovation illustrate the difference for soil compaction between cropping system (Table 11).

In general, sequential direct drilling is only suitable where the propensity for soil surface compaction can be alleviated or circumvented. Annual or regular direct seeding for pasture renovation meets the above criteria due to the concentration of crop residues at the soil surface. Maintenance of a surface mulch prevents the decrease in soil macroporosity, associated with compaction, and reduces the potential for relatively high water-filled pore space under humid to perhumid soil moisture regimes.

Use of rotational direct drilling appears suitable for spring cereals and silage corn. Under these conditions, periodic soil loosening during the rotational cycle will prevent an increase in soil compaction. In general, the duration of direct drilling will depend on levels of soil organic matter at the soil surface and the maintenance of optimum soil
Table II. Effect of direct drilling on a range of values for three soil compaction indices of a Charlottetown fine sandy loam, under three direct drilling systems.

<table>
<thead>
<tr>
<th>Direct drilling systems</th>
<th>No. of years direct drilled</th>
<th>No. of experiments</th>
<th>Bulk density (Mg cm$^{-3}$)</th>
<th>Macroporosity (% soil volume)</th>
<th>Depth to penetration resistance of 1.5 MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring cereals</td>
<td>3</td>
<td>2</td>
<td>1.32-1.43</td>
<td>8.5-13.0</td>
<td>13-15</td>
</tr>
<tr>
<td>Silage corn</td>
<td>3-4</td>
<td>2</td>
<td>1.34-1.40</td>
<td>9.3-11.7</td>
<td>11-13</td>
</tr>
<tr>
<td>pasture renovation</td>
<td>3</td>
<td>4</td>
<td>1.28-1.35</td>
<td>12.3-15.0</td>
<td>18-30</td>
</tr>
</tbody>
</table>

*1Bulk density and macroporosity at the 0-8 cm soil depth. Generally a bulk density of $>1.4$ and macroporosity $<10\%$ indicate low soil aeration. Structure. Another alternative is the use of seed drill openers which provide maximum soil disturbance in the seed groove, or for row crops, the use of tillage within the seed row.

REFERENCES


SOIL TILLAGE SYSTEMS AND HERBICIDE TREATMENT LEVELS FOR WHEAT PRODUCTION AND SUBSEQUENT PASTURE REGROWTH ON A MEDITERRANIC SOIL

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ABSTRACT

Wheat cv Nazareno Strampelli was sown after three methods of soil tillage with different herbicide treatments on a grass-legume ley. The regrowth of the pasture was monitored in the following season. Tillage treatments did not affect seed germination, root growth, water use and yield of the wheat. However both soil tillage and herbicide level influenced weed growth and there was a significant interaction between treatments. Pasture regrowth after the cereal was markedly affected by treatments. Seed reserves in the top 5 cm of the soil was greatest when wheat crop was direct-drilled. In the pasture phase total dry matter production and that of legumes were highest after direct-drilling. Conventional tillage decreased total herbage specially legume dry matter production. Simplified tillage using a tine scarifier gave an intermediate production of dry matter but with a greater content of grasses. Increasing the application of herbicides to the wheat reduced growth of the following pasture. However post-emergence hormonal herbicides increased the proportion of legumes present due to a decrease of competition with broad leaves weeds.

INTRODUCTION

In Southern of Portugal the traditional agricultural system is to plough out a grass-legume fallow after a number of years, depending on soil fertility, and sow a cereal crop, usually wheat. With the entry of Portugal into the European Economic Community there is a need to maintain, at least, the productivity of both crops while reducing total production costs. Soil tillage is, in the present moment, a main component of total cost of the production.

The three most frequent objectives of soil tillage are: (1) preparation of a seed bed; (2) weed control; (3) improving root growth.

Pasture usually provides a good entry for cereals due to better soil structure, an increase of nutrients level and easier weed control if correctly grazed. There is an opportunity to take advantage of these benefits and reduce inputs to a cereal crop. However, the pasture regrowth after the cereal will depend on the amount of seeds left in the top soil after cultivation of the cereal and residual effects of herbicides used during cereal might constrain pasture regrowth. The total cost of the system will then depend on soil tillage methods and herbicides usage during wheat production.

MATERIALS AND METHODS

Treatments and Lay Out - In November 1985 Nazareno Strampelli wheat was sown on a nine years old grass-legume ley. Treatments were in factorial combination in a split-plot design. Soil tillage treatments formed the main plots. Treatments were:

Soil Tillage (3): (Conv.)-plough at Autumn (25 cm) followed by two disk
harrowings; (Red.)—two passes of a shallow tine scarifier (5–10 cm) before seeding; (D.D.)—spraying of 2 L ha⁻¹ of paraquat followed by direct drilling

Herbicides (3): (0)—without herbicide (except 2 L ha⁻¹ of paraquat on direct drilling plots); (1)—2,4D + MCPA as post-emergence hormonal herbicide at the rate of 1,5 L ha⁻¹; (2)—pre-emergence herbicide (metabenstiazuron 2 kg ha⁻¹) plus post-emergence (2,4D + MCPA). These applications are less than are frequently applied.

Measurements

During wheat crop the measurements were: emerged plants m⁻²; grain production (g m⁻²); root growth at stem elongation and anthesis using the profil wall method; soil water profiles and crop water use from heading to harvest (mm) determined by neutron moisture meter; weed growth (dry matter g m⁻²) was assessed at anthesis.

For pasture regrowth the measurements were: number of seeds m⁻² in top 5 cm after soil tillage for wheat; total, grasses, legumes and others dry matter production (g m⁻²). The same measurements were done on a control area surrounding the trial where the pasture was kept during the wheat year. Seed reserves were counting dry sieving soil cores. Then residues were passed into perchoroethylene to remove soil and stones and seeds were hand separated from organic debris.

RESULTS

a) Wheat

Number of Emerged Plants m⁻² - there was no significant differences between treatments (table 1).

Wheat Root Growth - root growth was measured only for soil tillage treatments because the presence of weeds on the area of measurement invalidates the results. Tillage effects on root growth were smaller than soil variability (table 2).

Soil Water Profiles and Water Use Between Heading and Harvest - these measurements were made on soil tillage treatments with highest level of herbicides. There were no significant differences (table 3 and 4).

Wheat Yields - there were no significant differences (table 5).

Weed Growth at Wheat Flowering - traditional tillage gave a lower weed infestation (table 6). The increase of herbicide level increase weed control. There was an interation soil tillage and herbicides and the use of pre-emergence herbicide was more effective with reduce tillage.

b) Pasture Regrowth

Number of Seeds m⁻² - the differences between soil tillage treatments were highly significant (table 7).

Pasture Dry Matter Production:

Total - although soil tillage use for wheat production had a big effect on pasture regrowth the effects were only significant for herbicides (table 8).

Legume - soil tillage had a high significant effect on legume regrowth with direct-drilling giving the best result (table 9).

Grass - the effect of treatments were not significant on grass regrowth (table 10).

Others - the effect on this parameter was very much like the effect on total production (table 11).
DISCUSSION

WHEAT GROWTH AND PRODUCTION

a) Root Growth - The results are consistent with other findings that the effects of soil tillage are usually smaller than soil heterogeneity and that crops tend to produce deep roots faster under direct-drilling than under cultivation due to continuity of biologically produced pores.

b) Soil Water Profiles and Water Use - Soil water profiles at wheat heading (end of the season where rainfall is higher than evaporation) suggested that soil tillage treatments did not affect soil water holding capacity. Soil tillage did not affect the ability of the crop to extract water according soil water profiles at harvest and water use between heading and harvest.

c) Wheat Yields - Treatments only affected wheat yield through weed control. According to these results a weed infestation of 50 g.m-2 dry matter can be tolerated without loss of yield.

d) Weed control - The only detectable effect of treatment was weed control. In this respect the interaction between treatments was mainly due to differential effects of pre-emergence herbicide in the three soil tillage treatments. Reduced cultivation resulted in a higher grass weed infestation and so the pre-emergence herbicide had the greatest effect on this treatment. However total weed control was unnecessary to achieve maximum yields. Pre-emergence herbicide was not necessary with conventional tillage and direct-drilling once the pasture had been killed off. Post-emergence hormonal herbicide gave better results with this treatment.

PASTURE REGROWTH

Only herbicides had a significant effect on total dry matter production. Although soil tillage had a great influence no differences were statistically significant. This was probably due to experimental design, to compare herbicide effects there were 12 degrees of freedom but only 4 degrees of freedom for comparing soil tillage effects. Soil tillage had a highly significant effect on legumes regrowth and use of direct-drilling for the wheat phase gave the highest yield of legumes in the pasture, higher than the original sward. Legume regrowth was significantly related with seed reserves in the top 5cm of the soil after soil tillage for wheat. We need to determine what the effects would be on total production if the composition of the original pasture were mainly legumes, as is desirable. The use of herbicides during the wheat crop decreases pasture regrowth, mainly due to residual effects of the pre-emergence application. Post-emergence hormonal herbicide applied to the wheat crop gave an intermediate pasture regrowth but a higher legume content probably due to a decrease of competition from broadleaf weeds.

The choice of the soil tillage system and herbicide level should be made according the benefits on the production of both wheat and pasture together with the relative costs. As the farm size in Southern of Portugal is frequently bigger than 500 ha, direct-drilling of wheat with the use of post-emergence hormonal herbicide would be more economical than the conventional tillage system because of: a) same level of wheat production; b) better pasture regrowth and higher legume content; c) lower direct costs; d) lower fix costs due to reduced tractors requirements.

CONCLUSIONS

1. On a fallow-cereal system in a mediterranean soil in Southern Portugal wheat production was the same with three contrasted soil tillage treatments.
2. Soil tillage and herbicide use for wheat production influenced yields
only by weed control. Total weed control was unnecessary to achieve maximum yields.

3. Subsequent pasture regrowth is affected by soil tillage and herbicide level use for wheat production. Herbicide level affects mainly the total pasture production and soil tillage the legume production.

4. Direct-drilling of wheat and the use of post-emergence hormonal herbicide can be a more economical solution than conventional practices.

Table 1 - Emergence plants m⁻²

<table>
<thead>
<tr>
<th></th>
<th>Herb. 0</th>
<th>Herb. 1</th>
<th>Herb. 2</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>D.D.</td>
<td>221</td>
<td>244</td>
<td>257</td>
<td>260</td>
</tr>
<tr>
<td>RED.</td>
<td>264</td>
<td>201</td>
<td>309</td>
<td>258</td>
</tr>
<tr>
<td>CONV.</td>
<td>217</td>
<td>204</td>
<td>279</td>
<td>233</td>
</tr>
<tr>
<td>Average</td>
<td>234</td>
<td>215</td>
<td>281</td>
<td>244</td>
</tr>
</tbody>
</table>

Table 2 - Wheat root growth (profil wall method - n=9 of countings)

<table>
<thead>
<tr>
<th></th>
<th>D.D.</th>
<th>RED.</th>
<th>CONV.</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth</td>
<td>Tillage rep.</td>
<td>Tillage rep.</td>
<td>Tillage rep.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-10</td>
<td>4892</td>
<td>4970</td>
<td>4013</td>
<td>n.s. p 5%</td>
</tr>
<tr>
<td>10-20</td>
<td>3035</td>
<td>2522</td>
<td>3198</td>
<td>n.s. p 5%</td>
</tr>
<tr>
<td>20-30</td>
<td>729</td>
<td>475</td>
<td>778</td>
<td>n.s. n.s.</td>
</tr>
<tr>
<td>30-40</td>
<td>219</td>
<td>129</td>
<td>135</td>
<td>n.s. n.s.</td>
</tr>
<tr>
<td>40-50</td>
<td>44</td>
<td>27</td>
<td>12</td>
<td>n.s. n.s.</td>
</tr>
<tr>
<td>50-60</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>n.s. n.s.</td>
</tr>
</tbody>
</table>

Table 3 - Soil water profiles (mm)

<table>
<thead>
<tr>
<th></th>
<th>Direct-drilling</th>
<th>Reduced tillage</th>
<th>Conventional tillage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(cm)</td>
<td>(cm)</td>
<td>(cm)</td>
</tr>
<tr>
<td>20</td>
<td>16.2</td>
<td>5.4</td>
<td>13.4</td>
</tr>
<tr>
<td>30</td>
<td>21.3</td>
<td>10.5</td>
<td>15.5</td>
</tr>
<tr>
<td>40</td>
<td>27.3</td>
<td>10.2</td>
<td>18.2</td>
</tr>
<tr>
<td>50</td>
<td>30.0</td>
<td>28.0</td>
<td>19.9</td>
</tr>
<tr>
<td>60</td>
<td>31.5</td>
<td>32.0</td>
<td>24.1</td>
</tr>
</tbody>
</table>

(no significant differences between treatments at any time and any depth)

Table 4 - Water use from head. to harvest (mm)

<table>
<thead>
<tr>
<th></th>
<th>D.D</th>
<th>RED.</th>
<th>CONV.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil</td>
<td>38.0</td>
<td>44.5</td>
<td>43.4</td>
</tr>
<tr>
<td>Rain.</td>
<td>102.8</td>
<td>102.8</td>
<td>102.8</td>
</tr>
<tr>
<td>total</td>
<td>140.8</td>
<td>147.3</td>
<td>146.2</td>
</tr>
</tbody>
</table>

(no sig. differences between treatments)

Table 5 - Wheat yields (g m⁻²)

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Herb. 0</td>
<td>Herb. 1</td>
<td>Herb. 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D.D.</td>
<td>153.5</td>
<td>187.5</td>
<td>166.8</td>
</tr>
<tr>
<td>RED.</td>
<td>116.9</td>
<td>162.8</td>
<td>170.8</td>
</tr>
<tr>
<td>CONV.</td>
<td>198.0</td>
<td>198.4</td>
<td>163.3</td>
</tr>
<tr>
<td>Aver.</td>
<td>155.0</td>
<td>182.8</td>
<td>166.9</td>
</tr>
</tbody>
</table>

(no sig. differences between treatments or replicas)
### Table 7

<table>
<thead>
<tr>
<th></th>
<th>herb.</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>Aver.</th>
</tr>
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<tbody>
<tr>
<td>D.D.</td>
<td>3009</td>
<td>1519</td>
<td>2777</td>
<td>2435</td>
<td></td>
</tr>
<tr>
<td>RED.</td>
<td>2199</td>
<td>1418</td>
<td>1258</td>
<td>1625</td>
<td></td>
</tr>
<tr>
<td>CONV.</td>
<td>521</td>
<td>607</td>
<td>897</td>
<td>675</td>
<td></td>
</tr>
</tbody>
</table>

Average 1909 1181 1644 1578

Tillage $F_{[2,4]} = 26.83 p < 1\%$

Herbicid. $F_{[2,4]} = 0.63\ n.s.$

Till $x$ Herb. $F_{[4,12]} = 0.39\ n.s.$

(yield of surrounding control area = 224.9)

### Table 8

<table>
<thead>
<tr>
<th></th>
<th>pasture (TOTAL DRY MATTER) (g.m$^{-2}$)</th>
<th>herb.</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>Aver.</th>
</tr>
</thead>
<tbody>
<tr>
<td>D.D.</td>
<td>280.4 188.5 158.8 209.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RED.</td>
<td>269.6 206.0 108.2 194.5</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>CONV.</td>
<td>171.4 121.5 96.2 129.7</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

Average 240.5 172.0 121.0 177.8

Tillage $F_{[2,4]} = 1.81\ n.s.$

Herbicid. $F_{[2,4]} = 9.58 p < 1\%$

Till $x$ Herb. $F_{[4,12]} = 0.59\ n.s.$

(yield of surrounding control area = 224.9)

### Table 9

<table>
<thead>
<tr>
<th></th>
<th>pasture (LEGUMES DRY MATTER) (g.m$^{-2}$)</th>
<th>herb.</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>Aver.</th>
</tr>
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<tbody>
<tr>
<td>D.D.</td>
<td>22.0 35.4 19.0 25.5</td>
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</tr>
<tr>
<td>RED.</td>
<td>8.3 10.7 12.4 10.5</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>CONV.</td>
<td>6.2 5.3 2.4 4.6</td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Average 12.2 17.1 11.3 13.5

Tillage $F_{[2,4]} = 21.03 p < 1\%$

Herbicid. $F_{[2,4]} = 0.59\ n.s.$

Till $x$ Herb. $F_{[4,12]} = 0.57\ n.s.$

(yield of surrounding control area = 8.1)

### Table 10

<table>
<thead>
<tr>
<th></th>
<th>pasture (GRASS DRY MATTER) (g.m$^{-2}$)</th>
<th>herb.</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>Aver.</th>
</tr>
</thead>
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<tr>
<td>D.D.</td>
<td>72.6 78.8 54.1 68.5</td>
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<tr>
<td>RED.</td>
<td>82.5 122.5 53.9 86.3</td>
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<tr>
<td>CONV.</td>
<td>49.4 61.9 48.2 53.2</td>
<td></td>
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</tbody>
</table>

Average 68.1 87.7 52.0 69.3

Tillage $F_{[2,4]} = 1.60\ n.s.$

Herbicid. $F_{[2,4]} = 0.35\ n.s.$

Till $x$ Herb. $F_{[4,12]} = 0.62\ n.s.$

(yield of surrounding control area = 122.3)

### Table 11

<table>
<thead>
<tr>
<th></th>
<th>pasture (OTHERS SPECIES DRY MATTER) (g.m$^{-2}$)</th>
<th>herb.</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>Aver.</th>
</tr>
</thead>
<tbody>
<tr>
<td>D.D.</td>
<td>187.8 74.5 84.5 115.6</td>
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<tr>
<td>RED.</td>
<td>178.8 72.8 41.9 97.8</td>
<td></td>
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</tr>
<tr>
<td>CONV.</td>
<td>105.1 54.2 45.1 68.1</td>
<td></td>
<td></td>
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</table>

Average 157.2 67.2 57.1 93.8

Tillage $F_{[2,4]} = 1.13\ n.s.$

Herbicid. $F_{[2,4]} = 14.0 p < 1\%$

Till $x$ Herb. $F_{[4,12]} = 0.79\ n.s.$

(yield of surrounding control area = 94.5)
DEVELOPMENT AND EVOLUTION OF THE ZONAL TILLAGE CONCEPT IN CHINA; A HISTORICAL REVIEW

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Heilongjiang Institute of Agricultural Modernization, Chinese Academy of Science, Harbin (People's Republic of China)

ABSTRACT

A number of traditional Chinese tillage practices is discussed in this paper. The history of these practices is described, based on archeological findings, like relics of ancient farm implements (as the plough share) and on old documents. The traditional practices are ridge farming and direct drilling.

The evolution of the different kinds of tillage systems, based on loose soil, a compact soil and a combination of these two (zones) respectively, is also discussed, with emphasis on their effect on soil fertility.

INTRODUCTION

The constitution of the tillage layer is the end-product of a tillage system, based on certain techniques and carried out with specific tillage equipment. The spatial structure of the layer determines the moisture, air and heat environment. These in turn, have an effect on the soil fertility, the activity of the micro-organisms and thus on growth and development of crops and finally yields. Since application of any tillage system to create a certain tillage layer involves costs, the choice of such a system also determines the economical benefits. Therefore, the tillage layer structure is the key problem in modern soil tillage research. Following is a study on this internal structure of the tillage layer, based on recent research findings, as well as on archeological findings and ancient Chinese documents.

OBSERVATIONS AND RESULTS

1. The traditional Chinese ploughshare has the shape of an equilateral triangle. Tillage with this implement leaves ridges and furrows on the soil surface.

2. The plough share developed in the Western world has a flat edge and a mouldboard with a special curvature to (partially) invert the soil and move it laterally. The bottom of the plough layer is flat.

3. In direct drilling or no-tillage systems, there is very little soil disturbance; the top layer remains compact.

4. The organic matter content in the compact zone of the zonal tillage system is higher than in the topsoil under a no-tillage system and in the full-field loosened system.
DISCUSSION

Generally speaking, the top soil layer created by tillage operations can be divided into three basic types:

a. an entirely loosened layer (full-field ploughing), where the uptake of soil nutrients and organic matter is higher than the input, so soil fertility will decrease.

b. an entirely compact layer (no-tillage system), where the soil fertility may be maintained due to a lower consumption and where crop yields often are lower.

c. alternating compact and loosened zones (chiselling at fixed intervals creating ridges), where the consumption of nutrients and use of organic matter is high, but where also the level of soil fertility is maintained.

The development and evolution of the zonal tillage (ridge) system.

The triangular ploughshare originated in the ancient Chinese agriculture. This was verified by the fact that all ploughshares unearthed in China, from the neolithic stone plough share, via the ancient brass ploughshares of the Western Zhou Dynasty, up to the ones found from the various dynasties of the Warring States, the Han, Tang, Song, Yuan, Ming, to the Qing dynasty, all are triangular, as is still the modern Chinese-style ploughshare (see Fig. 1).

In Fig. 2, the evolution of tillage implements through various dynasties is shown. Figure 3 shows the soil surface configuration, as created
by the various tools and implements, showing the evolution in time (from top to bottom) to the zonal tillage system.

Fig. 3

Development and evolution of the full-field ploughing system.

Repeated passes with the triangular ploughshare ("intensive tillage") will create a full-field loosened layer, as will also be created by one single pass of the mouldboard plough (see Fig. 4).

Fig. 4

The resulting flat plough bottom and inverted soil layer are the basic characteristics of ploughing, left unchanged throughout the evolution of ploughing equipment (Fig. 5). Figure 6 shows a number of developments in equipment design with resulting soil surface configuration.
Development and evolution of the no-tillage (direct drilling) system.

Leaving an entirely compact soil originated in the system using the "lei", a wooden stick to punch holes for planting (dibbling). This system later developed in "gourd sowing" and direct drilling, both widely practiced in China (see Fig. 7). The special no-tillage planters were developed later in the USA and Western Europe. Figure 8 shows the evolution of the direct drilling tools and equipment and the corresponding soil surface configuration, created by these tools.
The evolution of three main tillage systems with regard to their effect on the configuration and structure of the toplayer.

Fig. 9 gives a summary of the full-field ploughing (left), the ridge- or zonal tillage (center) and the no-tillage (right) system, as they have evolved in the course of history in China.

The zonal tillage concept is the quintessence of the fine tradition of "tillage guided by objective" from ancient Chinese agriculture.

One of the major objectives in exploiting our most valuable resource, the soil, has been to arrive at a sustainable agricultural production system, where the soil fertility is kept at a constant, sufficiently high level.
a. Soil tillage as a means to maintain the physical soil fertility, has never been fully acknowledged.

Soil tillage, crop rotation and application of farmyard manure, have been the three main pillars supporting Chinese agriculture for more than 5000 years. From these three, the maintenance of soil fertility in chemical and biological terms, by heavy application of manure, nitrogen fixing legumes and crop rotation has received ample attention and is world-wide recognised as the typical Chinese way of maintaining soil fertility. However, soil tillage has always been (quite wrongly) regarded as a simple measure to enable the utilization of the soil for the production of crops, and not as a means to influence the physical soil fertility.

The experience in traditional, ancient Chinese agriculture, that "tillage can fertilize the soil" has not been given due attention and was never studied in depth.

b. The superiority of the zonal tillage system becomes clear when studying the historical evolution of tillage methods.

Fig. 9 shows the development and evolution of Chinese tillage systems and their resulting tillage layer constitution. In this figure, it becomes clear that the zonal tillage system is the inheritance of the traditional Chinese ridge system, perfected in a number of aspects. The system combines the characteristic advantages of both loose and compact soil, while the disadvantages of each full-field system generally are overridden. The zonal tillage system resulting in a perfect structure and constitution of the arable layers, represents the modernization of the Chinese-style soil tillage, incorporating mechanization in the tradition of "tillage guided by objective" of ancient Chinese agriculture.

c. Tillage zones may maintain soil physical fertility on a sustainable level.

Research on these tillage systems carried out in many locations and for many years, has led us to the conclusion that the zonal tillage system not only gives higher yields over the others (i.e. full-field loose and full-field compact soil) systems, but in the course of time, the organic matter content of the compact zone (comprising up to 75 percent of the tillage layer volume) increases. So not only chemical and biological factors are responsible for the increase in organic matter content, but also physical factors, as these are affected by tillage.

The key explanation for these very positive effects of the zonal tillage system is most probably given by the existence of this compact zone, the undisturbed soil left by the triangular ploughshare used in traditional soil tillage. In this zone, humus build-up and conservation is improved.

In view of the apparent merits of this system, more research should directed toward the mechanisms involved in this system, in particular the role of the compact soil zone, in order to reveal the secret of "tillage guided by objective".
STRAW RESIDUE MANAGEMENT FOR AUTUMN-SOWN CEREALS GROWN ON A CLAY SOIL, 1979-1987

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² AFRC Institute of Arable Crops Research, Long Ashton Research Station, University of Bristol, Long Ashton, Bristol BS15 9AF, U.K.

ABSTRACT

Various cultivation treatments were tested on a clay soil with and without the presence of straw. Where straw was burnt high yields were obtained irrespective of cultivation treatment. Straw on or near the soil surface greatly affected the growth and yield of the subsequent crop. Both poor crop establishment, because of physical blockages of the drill and slug damage, and Cephalosporium stripe (Cephalosporium gramineum) were important factors involved. Incorporation to 15-20 cm overcame the major growth effects and reduced the yield penalty. Volunteers were a problem where straw was shallowly incorporated but were controlled by a combination of burning and deeper ploughing.

INTRODUCTION

During the 1970s and the early 1980s the area and production of cereals increased in the U.K., and with the expansion, more straw was produced adding to the already considerable annual surplus, estimated at 1.5 million tonnes in England and Wales in 1983. Where no local demand for straw existed farmers disposed of their surplus on the farm and much of it was burnt.

Straw burning and straw incorporation into the soil are the most practical methods for the disposal of surplus straw. A recent survey of the pattern of cereal straw disposal in England and Wales (Anon, 1987) shows that 27% of the total cereal area was burnt, 18% was incorporated and the remaining 55% was baled and removed.

Cultivation experiments on a range of soils in the principal cereal growing areas indicated that, if straw was burnt direct drilling or reduced tillage could give yields of autumn-sown cereals that were equal to those after ploughing. There were however indications that these reduced cultivation systems were less satisfactory when straw was present.

A number of experiments have been made to test reduced tillage systems in the presence of straw. Christian et al., 1988b (these proceedings), gave results from two such annual experiments comparing straw incorporation at different depths to 30 cm. A long-term experiment was started on a clay soil at Northfield, near Wantage in Oxfordshire in the autumn of 1979. Preliminary results have been given by Graham et al., (1986), further data from a limited set of treatments are reported here.
METHODS AND MEASUREMENTS

Straw disposal methods have been tested on continuous winter cereals. The experiment is being conducted on a clay soil (Lawford series) containing 21% (w/w) sand (60 μm-2 mm), 40% silt (2-60 μm) and 39% clay (<2 μm) in the 0-19 cm horizon (Cannell et al., 1980). Winter wheat has been grown in each year except 1981, when the crop was winter oats.

Throughout the experiment straw burning has been compared with chopping and spreading with a straw chopper mounted on the combine harvester; treatments were cumulative. These treatments were followed by sowing either by direct drilling or after cultivation to 5 cm. Subsequently additional depths of cultivation were included (see Fig. 1 for details). In 1985 the cultivation method was changed from tine/disc cultivation to ploughing.

Crop growth was measured on several occasions and at harvest when the yield was estimated by combine harvester. Numbers of volunteer cereals were estimated after ear emergence in 1987.

Crop disease assessments were made from 1983 onwards. Slug numbers, estimated by the method described by Glen and Wiltshire (1986), and slug damage have been estimated each year since 1982.

RESULTS AND DISCUSSION

Yield

Burning the straw followed by each method of cultivation generally gave the best yield (Fig. 1). Differences in yield between the straw treatments were largest in the first 5 years of the experiment (1980-1984). The average decrease in yield because of the presence of straw was 32% after direct drilling and 19% after 5 cm cultivation. When straw was incorporated to 10-15 cm and 25 cm the comparable decreases were 11% and 8% respectively.

The presence of straw causes a number of interacting factors to affect the growth and yield of the following crop. Below we point to the factors that we think were important during the course of this experiment. A discussion of how straw may affect mechanisms involved in crop development can be found elsewhere in these proceedings (Smallfield et al., 1988).

Crop establishment

Direct drilling into chopped straw generally resulted in the smallest number of plants and least dry matter production at establishment.

Up to and including 1984, other treatments where chopped straw was incorporated tended to have fewer plants established and less dry matter produced than where the straw was burnt. Increasing the depth of straw incorporation increased the number of plants established and generally resulted in more dry matter production than after direct drilling into chopped straw.

Since 1984 most autumns were dry which made it difficult to control volunteer cereals especially after shallow incorporation and this
resulted in an increase in the number of plants. As a result it was not possible to accurately assess dry matter production by the sown crop. On the burnt treatment no marked change in the number of plants established was recorded. Burning the straw and ploughing-in the ash to below 15 cm was the only treatment that effectively controlled volunteers.

The probable factors causing the reduction in plant numbers and dry matter production at establishment are:

1. Physical blockages of the drill: Where the seed was direct drilled, poor establishment sometimes resulted from the failure of the disc coulters to penetrate surface straw and some seeds were placed into the straw or remained on the surface. Subsequently some seeds were eaten by slugs and birds.

2. Phytotoxins: Although phytotoxins resulting from the early stages of straw decomposition have been reported by a number of workers and their phytotoxic effects demonstrated in the laboratory (Harper and Lynch, 1981), we have been unable to detect their effect in the field. Under anoxic conditions in wet autumns and where seed and straw were in close proximity especially after direct drilling and very shallow incorporation, it is possible that phytotoxins contributed to poorer establishment.

3. Slugs: In the presence of straw, damage on direct-drilled plots by feeding slugs accounted for a large part of the reduction in the number of plants established in the autumns of 1982, 1983 and 1984 (Table I).

Table I. Slug damage to winter wheat in the autumn: effects of straw disposal and cultivation depth.

<table>
<thead>
<tr>
<th>Sowing date</th>
<th>Percentage of seeds and seedlings killed by slugs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Burnt 0cm 5cm 10-15cm 25cm Chopped 0cm 5cm 10-15cm 25cm</td>
</tr>
<tr>
<td>1982</td>
<td>6 - - - - 47 - - - -</td>
</tr>
<tr>
<td>1983</td>
<td>6 5 5 - 36 10 14 - -</td>
</tr>
<tr>
<td>1984</td>
<td>0 1 1 1 26 6 7 4 1</td>
</tr>
<tr>
<td>1985</td>
<td>1 0 0 1 14 4 1 1 1</td>
</tr>
<tr>
<td>1986</td>
<td>0 0 0 0 1 0 0 1 1</td>
</tr>
</tbody>
</table>

There was much less damage in 1985 and 1986. In contrast the highest level of damage recorded where the straw was burnt was only 6% in 1982 and 1983 and about 1% or less from 1984 onwards. The pattern of slug damage from year to year did not closely follow slug numbers. In autumn 1982 when populations were about 150-180 per m² wet conditions favoured slug activity and damage, whereas in 1984 when populations were about 300 per m² there was a dry autumn and percentage damage was less probably because many volunteers contributed to total plant numbers. Slugs caused less damage to seeds and seedlings on cultivated than on direct-drilled plots.

Crop growth and development

The most marked effects on crop growth due to the presence of straw
were in the vegetative phase. These differences were reduced by compensatory growth in the period between stem elongation and harvest.

During the first 5 years of the experiment (1980-1984) measurements taken up to stem elongation showed that the straw treatments, especially where the crop was direct drilled, produced fewer shoots and dry matter than where the straw had been burnt. However, where straw was incorporated more shoots were produced and dry matter production was larger than where the crop was direct drilled into straw.

Up to 1984, before the volunteer cereals became an obvious problem, the individual grain weight and the number of fertile ears on plots with straw present were less than on equivalent treatments where straw had been burnt.

In the period 1985-1987 volunteer cereals, by adding to the number of plants and shoots present, may have partly compensated for any deleterious effects of straw. Volunteer cereals may have important consequences for grain quality and marketing.

Disease

During the first three years of the experiment (1980-1982), levels of disease were low on all treatments.

We observed no large differences in levels of leaf disease between areas where straw had been burnt and areas where straw remained. Root and stem-base diseases, especially take-all, tended to be more severe where straw was burnt, however this treatment gave the larger yields. The generally lower yields in 1985 and 1987 were associated with more severe levels of take-all on all treatments.

Cephalosporium leaf stripe, an uncommon cereal disease in the U.K., was prevalent on this experiment from 1981 to 1986 and was more severe where straw remained, especially where the crop was direct drilled. In the presence of straw, levels of Cephalosporium tended to fall with increasing depth of cultivation. These trends could explain some of the differences in yield in the period 1985 to 1986.

The level of Cephalosporium infection recorded in the crop tended to follow the same pattern as the number of slugs recorded, reaching a peak in 1985 and then declining. Because slugs feed on roots they may facilitate entry of this disease into the plant as shown by Slope and Bardner (1965) for other root pests. However, root damage caused by frost heave of the soil may also have occurred.

CONCLUSIONS

1. Simplified tillage and direct drilling have consistently given unacceptably low yields where straw was present.

2. Where straw has been burnt yields were similar irrespective of cultivation depth or direct drilling.

3. Where straw remains ploughing to 15 cm seems necessary to overcome the adverse effects of straw.
4. Levels of disease were unaffected by the presence of straw except Cephalosporium leaf stripe, which was more severe where straw remained. Cephalosporium is not commonly found under U.K. conditions.

5. Measures to control slugs may be necessary where straw remains on or near the soil surface.

6. Burning the straw and ploughing-in the ash to 15 cm or more provided an effective control of volunteer cereals.

REFERENCES


Fig. 1 Effect on combine yield of straw disposal, cultivation and direct drilling of winter cereals grown on a clay soil (1980–1987)

Notes: 1986 chop direct drill: hand harvest results
25cm cultivation (1985–1987) points not joined to aid clarity
THE EFFECT OF DEPTH OF STRAW INCORPORATION ON THE GROWTH AND YIELD OF WINTER WHEAT ON A CLAY AND A Silt LOAM SOIL

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ABSTRACT

On a clay soil and a silt loam soil, tillage/disc cultivation and ploughing were compared for incorporation of wheat straw (circa 9 t ha⁻¹) to depths ranging from 5 cm to 30 cm before the next crop was sown. Crops were also established by direct drilling into undisturbed soil. The effects of straw on crop growth and yield were identified by comparison with growth on areas where straw was burnt.

Compared with burning, leaving straw on the surface or incorporating it to 15 cm or less, caused large reductions in plant establishment and dry weight early in the season, but compensatory growth during late spring lessened the differences. On the silt loam soil direct drilling into straw reduced yield by 25% compared to burning, otherwise there were no yield differences between tillage depth or straw disposal method at either site.

INTRODUCTION

During the last 20 or 30 years a marked change has taken place in British agriculture. Farming enterprises have become increasingly specialised with cereal production in the more suitable climatic regions being aided by the favourable economics of cereal production.

Increasing cereal production has given more straw at a time when demand has remained relatively static. In a survey conducted in 1983, when straw burning was at or near its peak, about 42% of the 13.4 m tonnes of straw was burnt and only 2% incorporated into the soil, Anon (1983). Since then the amount incorporated has increased.

Burning surplus straw or incorporating it into the soil are at present the only practical alternatives available to the farmer. Burning has been popular because it provides a quick and efficient method of disposal, but it is now subject to many restrictions for environmental reasons.

Crop residue management is important for those soils liable to wind and water erosion. Incorporating straw returns nutrients and organic matter to soil but the rate of build up of soil organic matter will be slow. Benefits have been observed especially on light-textured soils in the UK (Mattingly, 1974). However where straw has been retained on or near the surface especially on heavy-textured soils, yields of following cereal crops have sometimes been decreased, (Oliphant, 1982; Graham et al.)
These effects can be directly attributed to the presence of straw because crops in its absence suffered no yield penalty when using comparable methods of tillage (Cannell et al., 1980).

Ploughing of clay soils is not easy and frequently requires considerable post-ploughing cultivation to prepare a seedbed. This slows the workrate and leads to a reduction in the area that can be prepared for sowing in a given time compared with simplified tillage (Patterson et al., 1980).

This paper reports the results of our experiments studying the minimum depth of cultivation needed to overcome the adverse effects of straw.

**METHODS**

These studies were carried out at two sites in Oxfordshire during 1983-1984. One experiment was situated on a well-structured non-calcareous clay soil (Denchworth series) at Buscot, near Faringdon, and the second experiment was on a silt loam soil at Charlton, near Wantage. Both sites had previously been under arable cropping. Both experiments were laid out as 3 randomised blocks, and wheat straw (estimated at 9 t ha\(^{-1}\)) was burnt on one plot in each block whilst on the other it was chopped and spread with a straw chopper mounted on the combine harvester. Part of each plot was left uncultivated and the crop direct-drilled. The remaining area of each main plot was sub-divided into 5 tillage plots at Buscot and two at Charlton. At Buscot three plots were cultivated with discs and tines to depths of 5, 10 or 15 cm and two ploughed to 20 or 30 cm. At Charlton one was tine/disced to 15 cm, the other ploughed to 30 cm. Subsequently seedbeds were prepared and the crop was sown using a single disc coulter drill (Massey-Ferguson 30) on the tillage plots and a triple-disc coulter drill (Massey-Ferguson 130) on the direct-drilled plots.

At Buscot, winter wheat cv. Rapier was sown at 400 seeds m\(^{-2}\) with 26 kg ha\(^{-1}\) of phosphorus and 50 kg ha\(^{-1}\) of potassium as a compound fertilizer. At Charlton, winter wheat cv. Avalon was sown (400 seeds m\(^{-2}\)) with 22 kg ha\(^{-1}\) of phosphorus. No autumn nitrogen was applied; in spring the dressing was 200 kg N ha\(^{-1}\) at both sites.

Appropriate chemicals were applied to minimise effects of weeds, pests and diseases. Plants were collected from each plot on several occasions so that plant population and growth could be assessed. At harvest, yield was estimated using a plot combine harvester (Claas Compact 25).

At Buscot, shortly after the straw was incorporated, 8 cores each of 15 cm diameter were taken on each plot on one replicate. Straw was collected from the surface of the core and recovered from each 5 cm layer of soil. The straw was washed, dried and weighed.
RESULTS

Straw burial

The proportion of the straw recovered from the soil surface amounted to 47%, 44% and 20% following cultivations to 5, 10 and 15 cm respectively. Much more straw was buried by ploughing to 20 cm or 30 cm and for these treatments the average amount recovered from the surface was only 4%. Ploughing placed a larger proportion of the chopped straw deeper in the loosened topsoil compared with tine cultivation. Less straw was recovered in the 0-5 cm soil layer after ploughing (6%) than after tine cultivation (31-45%).

Plant establishment, growth and yield

At both Buscot and Charlton, direct drilling through a surface layer of straw resulted in a significantly reduced number of plants established compared to direct drilling after burning the straw (Table I). At Buscot, where much straw remained on the surface following tillage to 5, 10 or 15 cm, the number of plants that emerged was also smaller compared to the number after burning. At both sites, cultivation to a depth greater than 15-20 cm greatly reduced the differences in plant population between plots with and without straw.

Table I shows that in autumn, with the exception of the deepest cultivation, the dry matter production from plants growing on plots with straw was much less than on plots where straw was burnt. On the latter, differences between plots were small and little affected by depth of cultivation. At Charlton there was no difference in dry matter production where straw was burnt or remained after ploughing to 30 cm. At this site all plots lost some plants during the winter. Where straw was present the percentage losses were greater than where the straw was burnt. At Buscot there were no consistent effects on winter survival.

Table I also shows that in April at both sites plants growing where straw was present remained smaller than those where straw was burnt, particularly after direct drilling. At both sites the relative increase in total dry matter between April and June was much greater on plots with straw present and cultivated to 15 cm or less than where straw had been burnt.

At Buscot the grain yield was similar and greater than 11 t ha⁻¹ on all treatments. Yield at Charlton was also large, but direct drilling with straw present resulted in a significantly lower yield compared with the other treatments. This difference was related to a lower grain mass and smaller number of grains per ear rather than to number of fertile ears.

DISCUSSION

Results at both sites indicate that straw affected crop germination and early growth. At Buscot the range of tillage depths tested indicated that adverse effects are largely overcome by tillage to 15-20 cm or more, an observation supported by the fact that at Charlton the number of plants established following cultivation to 30 cm was the same with and without straw, and effects on plant size and dry matter production were also prevented by the deeper incorporation of straw.
Assessments of the location of straw in the soil profile after cultivation showed that after tine cultivation there was much more straw on the surface and shallowly incorporated than after ploughing. Tine cultivation relies on a sifting effect to bury straw (Kouwenhoven and Terpstra 1979); and increasing the depth of tine cultivation did not substantially alter the depth of straw incorporation. Similarly, direct drilling places seed in close proximity to straw which is concentrated within 2-3 cm of the planted seed. The effects on plant population and dry matter production were related to the proximity of seed and seedling to the straw, and are largely consistent with results obtained in an experiment with winter oats at a nearby site (Christian and Miller, 1986).

No single causal agent for the poor establishment and growth on treatments was identified, but a number of different factors were likely to have been involved. For example, the poor placement of seed with some remaining on the soil surface or lodged in straw made it easy for birds to take seed and slugs to feed. Seedlings growing very shallowly are more easily killed in cold weather during the winter. The influence of toxic substrates leaching from decomposing straw may also have had an effect as well as the sequestration of nitrogen following the ill incorporation of a large quantity of straw (Smallfield et al., 1988).

The results showed that in spring, where straw was present, compensatory growth took place. Environmental conditions for growth were exceptionally good in spring 1984 which may have helped reduce the impact of poor early growth on yield. At Charlton direct drilling with straw present had little effect on the number of fertile tillers, and loss of yield was associated with low grain weight and low number of grains per ear. We can offer no explanation why straw should have affected these components of yield on this treatment except that it probably occurred during the period of tiller development.

CONCLUSIONS

1. Without straw present and with minimal soil disturbance, winter wheat yielded well when sown on a clay and a silt loam soil.
2. With straw present, wheat direct drilled or sown after shallow cultivation had low plant populations and poor early growth.
3. Effects on establishment and early growth were much less when straw was incorporated to 15-20 cm or more.
4. Compensatory growth reduced differences between treatments and yields were only smaller after direct drilling into chopped straw on the silt loam soil. Nonetheless, direct drilling and shallow cultivation cannot be recommended as techniques for establishing cereals in the UK when straw residues are present.
5. The influence of straw on early growth suggests that it would be best to sow the crop into straw-free soil. This is best achieved by ploughing.
REFERENCES


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TILLAGE PRACTICES OF SUGAR CANE: EFFECTS ON SOIL POROSITY AND SOIL WATER RETENTION

PAULO C. CORSINI

1Faculty of agriculture, Department of Soil and Fertilizers, State of São Paulo University, Brazil.

ABSTRACT

The experiment was designed to study the effects of different systems of ratoon destruction associated with soil management practices on soil porosity and soil water retention of a red latosol soil cultivated with sugar cane (Saccharum spp. Na 5679), planted in March, 1979. The results obtained for five years showed that when soil was conventionally tilled there was a trend to effect these properties and this fact appears to be associated to a deterioration of soil aggregates although it improved the relation mass/volume of this soil for a short period of time.

Considerations were made about the importance of the quantity of organic matter accumulated on soil surface when the systems of ratoon destruction using glifozate was associated with a system of minimum tillage.

INTRODUCTION

The excessive use of a red latosol soil (Typic Eutrorthox) with sugar-cane in the State of São Paulo, Brazil, may markedly alter soil structure and indirectly soil physical properties, like porosity and soil water retention. In this crop the use of mechanical systems of tillage and the excess of agricultural traffic caused soil compaction and can impede root penetration, restrict aeration, reduce water conductivity, may improve soil erosion, reduce yield, improve the consumption of energy and increase the absolute and relative costs of production. One obvious way to reduce the extent and subsequent impact of the modifications in soil structure is to limit or control agricultural traffic (Soane et al., 1979). Another way is to improve soil structure and maintain this condition for a long period of time (Corsini, 1979).

In order to study the soil structure management the soil scientists in South America have developed research projects studying the effects of different tillage systems where pertinent soil physical properties are measured before and after defined tillage operations and during the entire cycle of the crop. (Lugo Lopes and Azevedo, 1956); (Sanchez, 1976); (Coletti and Dematté, 1982); (Camargo, 1983) and (Corsini, 1986).

In a general way the results point out that the poorer the soil structure the more it must be tilled and the more the soil is tilled the poorer the structure becomes. By using technique of no-tillage the soil scientists try to break this discouraging cycle allowing organic matter renewal to take place naturally within soil from loosening effects of crop roots and from decaying crop residues. However, they, only use these techniques if soil has adequate physical, chemical and biological characteristics. Several minimum tillage methods required starting with plowed land and considerable disturbance of soil profile and other operations (Young, 1978) and (Corsini, 1987).

Aware of this problem and the fact that sugar-cane crop has occupied large areas of the red latosol soil an extensive program has been conducted to establish quantitative and qualitative informations about the influence of sugar-cane systems of tillage on physical characteristics of this soil,
on soil-water-plant relations and on the crop (Corsini, 1972, 1974, 1986 and 1987) and (Casagrande et al., 1975, 1981).

In this research, part of this program emphasized the effect of ratoon destruction associated with soil management practices adopted for sugar cane culture and other practices introduced in this work on soil water retention function, soil pore-size distribution and soil structural conditions as a functions of time and soil depth.

MATERIAL AND METHODS

A factorial experiment was established in December, 1979 at the Santa Lídia Sugar-mill in Ribeirão Preto county, State of São Paulo, Brazil (21°01'5S, 47°49'W, elev. 560 m a.s.l.) on a red latosol soil with a heavy texture and a compact Acr horizon using variety Na 5679. Treatments included two systems of ratoon destruction: (A) - mechanical elimination and (B) chemical elimination using herbicide (480 g/l) of salt isopropylamine of gliphosate and five combinations of the following types of soil preparation 1-heavy disc-harrow + level disc-harrow + forrowing on the rows; 2-sub-soiling + level disc-harrow + forrowing on the rows; 3-sub-soiling in two directions (15-20°) + level disc-harrow + forrowing on the rows; 4-heavy disc-harrow + level disc-harrow + forrowing in the interrows and 5-Minimum tillage + forrowing in the interrows using special machinery for no-tillage. In the treatment B6 the mulch resulting of the three harvest was maintained on soil surface.

The ratoon destruction (treatment A) was done by using a conventional method and the chemical elimination (treatment B) was done when ratoon was 1.60 meters height and gliphosate was broadcast applied at a rate of 6.0 l/ha.

Using fritted glass-bead plates for membrane material in the suction range 0 to 0.1 atm of water, Nielsen (1958) and ceramic plates, Richards (1949) in the suction range 0.1 to 0.8 atm, the soil water retention and soil pores size distribution was determined for three undisrupted soil cores (60 mm diam, 60 mm depth) obtained from several treatments and four dates. The first one after the experiment installation (December, 1979); the second one right after the first harvest (June, 1981); the third one right after the second harvest (July, 1982) and the fourth one right after the third harvest (August, 1983). Samples of the different treatments were taken on the same day at three positions, one in the depth of 1-7 cm; the second in the depth of 20-26 cm and the last in the depth of 40-46 cm, by using a special sampler.

The soil moisture (θ cm⁻³ cm⁻³) and the free porosity (S cm⁻³ cm⁻³) were determined at the following matric potentials of soil water (ζ-atm): 0.0; 0.06; 0.33; 0.60 and 0.80 atm, interval where structure alteration modifies these relations (Sharma and Uehara, 1968 and Corsini, 1972).

In order to evaluate the differences in the values of soil moisture and free porosity for each tension in considered factors the data was analysed by using a factorial 4x2x5x3 respectively four dates of sampling; two systems of ratoon destruction; five tillage systems involving several types of soil preparation and three depths of sampling.

Because there were no repetitions, the interactions greater than two were used as a residue. Regression procedure was used to study the function ζ = (θ, S) for all depths, treatments and dates. These equations were compared by an analysis of variance of their coefficients.
RESULTS AND DISCUSSION

By the results of the analysis of variance of the relations between θ, S for a specific value of ζ, in the studied interval, considering four dates of sampling, two types of ratoon destruction and five treatments and three depths it was observed that there was a decrease in these values as a function of the date of sampling mainly for smaller values of matric potential, for S values and for the superficial layer. In a general way no significant differences were found between the interactions, except for the interaction type of elimination and systems of soil preparation. The variation of pressure distribution and compaction under tractor tyres, the variation of the traffic of machinery and the position where the samples were obtained may explain the differences found in these treatments.

The functional relation between θ and S for the studied interval of ζ was obtained by employing a power function.

The power function had the following form: ζ = ab (ζ = ab^S). The r values obtained from the linear analyses (lnζ xθ or S) performed on all relations ranged from 0.96 to 0.99. The two constants A and B which were necessary to describe these relations, were not independent. Linear regression analysis of A and B of the equations lnζ = A + Bθ and lnζ = A + BS were done for the superficial layer and for the depth of 20-26 cm and 40-46 cm. In all cases they showed a good correlation.

There were not significant differences in the parameters of these functions for the four dates of sampling in the superficial layer and for the interactions dates x soil preparation and dates x ratoon elimination except for the soil pore-size distribution function, were there was a tendency of variation in the interaction type of ratoon elimination x soil preparation. In a general way there were no differences in these parameters in the association systems of soil preparation and mechanical ratoon elimination, the same occurring with the treatments B1, B2, B3 and B4, although they were different from B5 treatment.

These tendencies and variations could be analysed by linear equation and the coefficient A was chosen to serve as an index of the value of θ in the absence of tension (ζ=0) and could be used as a measure of soil total porosity. In the A1, A3 and A4 treatment the A values increased as a function of time after soil preparation (1,068; 1,4527; 1,7538 and 1,7920) for A1 and (1,1857; 1,228; 1,2289 and 1,2353) for A3 respectively for the four dates of sampling. The inverse occurred in the treatment A2 and A5 (1,3680; 1,2882; 1,1733 and 1,1692) for A2 and (1,857; 1,2281; 1,2289 and 1,2353) for A5, respectively for the four dates of sampling.

In the first case the soil preparation systems using heavy disc-harrow and subsoiling associated with the mechanical ratoon elimination decreased the relation mass/volume as a function of time and improved the total porosity in the superficial layer. In the second case involving the subsoiling and minimum tillage associated with mechanical ratoon destruction and forrowing in the interrows the total porosity decreased as a function of time and could be explained by the predominance of the effects of traffic over the little mobilization of soil in this layer.

In the treatments B1, B2 and B3 the A values decreased as a function of time for the period between the first and the second date of sampling and increased in succession except for the treatment B4 were the A values decreased for all studied period. For example the values for B1 were 1,2523; 1,1636; 1,304 and 1,386 and for B4 were 1,6084; 1,0286; 1,0042 and 1,0036, respectively for the four studied dates for sampling. After
the third date of sampling the A values, in the B5 treatment improved as a function of time.

After three years the total porosity in the treatment B5 was improved and this condition could be explained by the protection of the mulch against traffic and by the tendency to improve the moisture and the aggregation in this layer.

In a general way in the 20-26 layer there was no significant differences in the parameter A of the function \( \ln \xi = A + B \theta \) although the B values showed significant variations as a function of time and for the effect of soil preparation treatment. The smallest media were found in the treatment A3, A5, B1 and B5 mainly in the B5 were a tendency to decrease the \( \theta \) values for the following values of tension (0.06; 0.1 and 0.0).

It was observed that the studied parameters affected the function \( \ln \xi = A + B \theta \) mainly for soil preparation. Independent of ratoon destruction the treatment which involved heavy disc-harrow and subsoiling decrease free porosity values as a function of time, although they improved these values in the period between the first and the second date of sampling. In the B5 treatment there was a tendency to decrease these values between the first and the second date and to maintain these values in succession.

In 40-46 layer the functions \( \xi (\theta) \) and \( \xi (S) \) were affected only by the treatment that involved heavy disc-harrow and subsoiling and this effect was maintained for a longer period of time independent of the type of ratoon destruction. In the treatment B5 there was no variation and this aspect could be explained because no mobilization was done in this depth.

By general analysis of all variation and tendencies of these interdependent functions influenced by different systems of tillage, some aspects must be enumerated. The soil preparations using heavy disc-harrow, subsoiling, independent of the type of ratoon destruction, decrease the soil mass/volume relation for a short period of time and the maintenance of this effect depends on depth of the layer.

This evidence clearly indicates that the conditions of climate of this tropical region associated with the operational systems of sugar-cane management affected markedly these properties and must be more studied.

Although these systems of tillage are very expensive their effects on soil water retention and on soil pores size distribution was not significantly affected for the studied period and showed the tendency of damaging soil structure and their dependent soil-water relations.

After 1982 there was a tendency to improve these relations in the superficial layer in the reduced tillage treatment (B5). This effect was related to the mulch quantities maintained on soil surface, its degree of decomposition, its protection against tractor tires pressure, intensive traffic and others operations practices. Under this material a granular fine soil structure was developed.

This evidence explained the results obtained in the works of Casagrande et al. (1981) that the permeability and porosity of a red latossol soil cultivated with sugar-cane were improved when the systems of tillage involving sub-soiling operations were used, although did not affect the crop yield. This improvement occurred for a short period of time and did not affect the sugar-cane yield.

The results on the sugar-cane yield showed that there no significant differences between the treatments except for the results obtained after 1982 in the B5 treatment (Corsini et al., 1987). This evidence clearly
indicates the importance of the use of reduced systems of tillage, the maintenance of the rests of this culture and in consequence, the necessity of development of alternative practices of soil-culture management adapted to this system mainly in the operational point of view, for example: the application of lime, the problems of planting, the problem of fire and the possibility of physical properties recuperation of this soil by using plants that had a higher potential for soil recovery, that had a large volume of roots and that had developed large quantities of mulch during sugar-cane renovation period. Important studies were developed with this objective by (Rosa, 1981) and by (Cintra and Mielniczuk, 1983).

CONCLUSIONS

The soil moisture and the soil pore-size distribution interdependent function were described in the studied interval by a power function: \( \zeta = ab^\theta \) (\( \zeta = ab^\theta \)).

In a general way the systems of tillage using mechanical soil preparation decreased the soil mass/volume relation for a short period of time and the subsistence of this effect on soil water retention and on soil pore-size distribution functions depends on soil depth and their influence on soil structure. It was observed the importance of maintaining the rests of the culture on soil surface and the necessity to improve the physical, chemical and biological properties of this soil before using minimum tillage practices. In this way these practices improved the soil structure after three or more years.

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INFLUENCE OF LONG-TERM MINIMUM TILLAGE ON SOIL PROPERTIES AND YIELDS

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ABSTRACT

Investigations are based on an 8-year-field trial testing conventional tillage in comparison to minimum tillage, carried out on a minimum tillage farm in a corn-wheat crop rotation. The investigations comprise influences of the different tillage systems on soil properties such as content and distribution of organic matter, nutrients and pH, soil structure, microbiology and earth worms, and economic aspects such as yield and input in labour and pesticides.

The preliminary result is that the minimum tillage system described can compete with the conventional system at a low intensity level economically. It is advantageous with respect to erosion control and biological activity (especially earthworm population).

INTRODUCTION

Many field trials have been carried out in recent years in order to find out if a ploughless tillage system can compete with the conventional system in which the plough is a basic implement. Such trials often suffer from several disadvantages: mostly too short a testing period, insufficient technical equipment, and lacking experience of the technical staff in handling a new tillage system especially in finding the most suitable point of time for carrying out the required tillage work (which is not the same for both tillage systems). Frequently, such comparisons favour the conventional system, especially, if the minimum tillage system is tested on a farm where ploughing is customary (misleading experiments).

In order to avoid the above mentioned mistakes we established our field trial on a minimum tillage farm, using the fields of the farm and the experience of the farmer in minimum tillage for the comparison.

METHODES

The trial is carried out on a 240 ha-farm with a wheat-corn-crop rotation.

Location: near Ingolstadt (Upper Bavaria)

Soil: Parabraunerde (Typic Hapludalf); parent material: loess; mean precipitation: 650 mm; mean temperature: 7.5 °C

Trial variants

I. Minimum tillage (as carried out by the farmer)

Tillage: restricted to a rotary cultivation about 5 cm deep combining both seeding and fertilizing. For this purpose a new seeding device was developed by the farmer, the "Saexaktor".
Seeding: broadcast seeding, unequal seeding depth, straw remains mostly at the surface (mulch seed)

Pesticides: weed control is mainly done by herbicides; fungicides are not used.

II. Conventional tillage
Tillage: stubble treatment by chiselling after wheat, ploughing 25 cm deep in the fall

Seeding: seedbed preparation with a rotary harrow, conventional seeding device (row seeding)

Pesticides: reduced herbicide application; fungicides are not used.

Fertilizing as under I.

III. Conventional tillage
Tillage, seeding and herbicides as described under II, additional fungicide application, fertilizing increased

The investigations include the impact of the different tillage methods on soil, plant growth, yield, and economy. The 3 trial variants described are part of a larger field trial where comparison between I and II points out the effect of the different tillage work, in variant III we tried to optimize the conventional system for economical comparisons.

The following investigations were carried out:
bulk density (volumetric method); pentrometre measurements; earthworm population, using methanal for expulsion; microbial biomass (Anderson et al., 1978); nutrients (phosphate, potassium, CAL), organic carbon and pH (CaCl₂) and their patterns of distribution in the (former) plow layer; infiltration (double-ring infiltrometre), runoff and erosion using a Swanson type rainfall simulator (Auerswald, 1984); observations of plant growth; yields and economic calculations (gross return minus variable costs).

RESULTS

Nutrients, organic carbon, pH

![Graphs showing nutrient levels](image-url)
While phosphorus, potassium and organic carbon in the conventional system are distributed about evenly throughout the whole plough layer these elements are strongly enriched in the rotary cultivated top layer of the minimum tillage system which contains all crop residues and a main part of the roots. The pH-value of this layer is about half a unit lower (both systems are unlimed).

**Bulk density, penetration resistance**

The graphs represent the mean values of bulk density of 8 years. Measurements were carried out before tillage in springtime and before harvest in fall. Bulk density in the minimum tillage system is considerably higher than in the conventional system, especially in the untilled layer below the rotary cultivated top soil, where bulk densities of 1.63 - 1.65 were determined.

The high bulk density of this layer is also indicated by the penetrometer. Here an additional subsoil compaction (plough pan) can be recognized which is predominant in the conventional system.

**Microorganisms**

For the minimum tillage system the highest microbial biomass concentration is determined in the rotary cultivated layer, whereas for the conventional system it is found in the lower part of the plow layer. The same tendency can be observed for the content of organic carbon (Corg) and the percentage of the microbial biomass related to organic carbon (Cmic/Corg). Related to the whole plough depth the values for the conventional system are constantly higher: for Corg about 10%, for biomass about 31%.
Earthworm population

The graph indicates an alarming decrease of worms as a consequence of conventional tillage (compare Ia and III). Obviously there is no effect of different fertilizing and pesticide treatment (compare II and III). The abundant application of herbicides in the minimum tillage system (Ia) is not harmful to worms either. However, the removal of crop residues (Ib) causes a strong diminuation of worm individuals and an even stronger diminuation of worm biomass due to food deficiency striking especially the adult animals.

Infiltration

Measurements were carried out at the surface of the cornfield shortly before harvest time. The results represent the permeability of the soil at the end of the vegetation period showing a much greater infiltration rate in the minimum tillage system.

Erosion control

In the minimum tillage system crop residues remaining at the surface and better permeability provide a very effective erosion control. Under the given conditions minimum tillage diminishes runoff about 50 %, eroded soil to about 10 %.

Runoff and soil erosion depending on the tillage system

<table>
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<tr>
<th>system</th>
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<th>runoff %</th>
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<td>45</td>
<td>29,6</td>
<td>26,7</td>
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Trial conditions: slope 6 %; K-factor 0,51; time of irrigation May (emergence of corn), 65 mm in 60 minutes, applied by rainfall simulator.

Plant growth

In spring time the minimum tillage broadcast seed produces a smaller number of wheat plants but later on, due to a better tillering, about the same number of stems is reached as in the conventional system. Concerning plant diseases there were no significant differences between both systems. The broadcast seeded corn appeared to be less uniform and lagged behind the conventionally seeded one in height but was better in cob development.
Yields

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<th>Year</th>
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<th>Corn (t/ha)</th>
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<td></td>
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<td>6.04 5.70 7.63</td>
<td>7.08 7.89 7.00</td>
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*) Lodging by thunderstorm, in Ø excluded

Economy

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<td>1983</td>
<td>162 117 117</td>
<td>240 25 25</td>
<td></td>
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<tr>
<td>1984</td>
<td>- - 252</td>
<td>- - -</td>
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<tr>
<td>1985</td>
<td>265 265 364</td>
<td>282 282 350</td>
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<tr>
<td>1986</td>
<td>243 375 424</td>
<td>265 412 412</td>
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<td></td>
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<tr>
<td>1987</td>
<td>190 180 226</td>
<td>660 757 683</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Ø</td>
<td>1064 1141 1587</td>
<td>1687 1716 1710</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

DISCUSSION

The tillage systems presented affect soil properties in many respects. It is an open question if the shallow incorporation of nutrients in the minimum tillage system is disadvantageous in the long run. Obviously the more intensive root system and the bigger amount of incorporated crop residues result in a stronger decrease of pH in the rotary cultivated layer of the minimum tillage system.

The conventional system favours the content of organic matter (Corg) and microbial activity (biomass) related to the 25 cm top soil but the higher values of Corg and microbial biomass in the 5 cm surface layer of the minimum tillage system are probably more advantageous.

In spite of the much higher bulk density of the no longer ploughed top soil the infiltration rate is considerably higher in the minimum
tillage system. Obviously there is a relation to the numerous worm holes reaching up to the soil surface and to the better resistance of the surface layer against splash due to the higher concentration of organic matter and biological activity.

Economically the minimum tillage system turns out well on the investigated low intensity level (comparison between I and II) but it is questionable if it can compete with the conventional system at a higher level of fertilizing and pest management (in III the maximal net return was probably not yet reached).

The attempt of growing sugar beets has shown that the minimum tillage system is not appropriate for this crop. Potatoes are out of the question as well. Even corn for silage is higher in yield with conventional tillage.

The crop residues remaining at the surface reduce runoff and erosion considerably. On the other hand they favour some pests, for example snails, in some areas the corn borer is a menace.

The high input of herbicides is considered to be a serious disadvantage of the minimum tillage system. It is growing with increasing weed problems and herbicide costs. On light textured soils the mechanical weed control (using the plough as a very effective implement) may be cheaper.

CONCLUSION

The described minimum tillage system is an interesting alternative to the conventional system for bigger farms with special rotations which don't aim at maximum yields. It will gain importance if the costs rise with prices declining at the same time. In areas susceptible to erosion it certainly contributes to soil protection.

REFERENCES


Acknowledgement

We should like to thank our colleagues for their contribution to this report, Dr. J. Bauchhenß (earthworm population), Dr. Th. Beck (microbiology), Dr. H. Borchert (soil physics) and Dr. M. Kainz (erosion control).
The physical condition of a fine cultivated sandy loam in central northern Nigeria was closely associated with the degree of soil disturbance. Unlike manual ridge-splitting, all-over tractor-powered tillage affected the soil's physical condition adversely but enabled crop residues to be incorporated and assisted weed control. Maize yield, but not cotton, was positively correlated with soil disturbance but this was probably largely due to a nutritional benefit derived from incorporated crop residues. Ridge-splitting and primary disc harrowing were the most energy efficient tractor-powered tillage systems.

METHOD

The experiment occupied 2.5 ha on a moderately well-drained mid-slope at the Institute for Agricultural Research, Samaru, Nigeria (11°31' N, 7°38'E). At the start, a bush fallow of at least 10 years duration was cleared and destumped manually. Average clay content increased from 14% in the fine sandy loam topsoil to 35% in the subsoil. In the FAO/UNESCO Soil Map of the World, the soil is a ferric luvisol. Its physical properties have been described by Kowal (1968). Average rainfall during the study (1977-82) was 950 mm, nearly 15% below the long term average.

There were three ridge-splitting systems, five all-over tractor-powered systems and zero tillage (Table 1). Ridge-splitting (MAN, OXT & TRS) involved breaking the previous year's ridges and creating new ridges over the old furrows without prior disturbance. In the all-over tillage systems the secondary operations were disc harrowing and ridging (TDR, TDP...
& TMB) or spring tooth cultivation followed by planting on the flat (TSB & TDF). In zero tillage (ZRT) the soil profile inherited from the previous fallow was preserved largely intact while vegetation was suppressed by either paraquat or glyphosate, supplemented by cutting.

Table 1  Details of tillage systems

<table>
<thead>
<tr>
<th>Code</th>
<th>Name</th>
<th>Primary operation and depth (mm)</th>
<th>Ridged or flat</th>
<th>Fate of maize residue</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAN</td>
<td>Manual tillage</td>
<td>Ridge splitting with heavy hoe (80)</td>
<td>Ridged</td>
<td>Removed</td>
</tr>
<tr>
<td>OXT</td>
<td>Ox tillage</td>
<td>Ridge splitting with ox-powered ridger (80)</td>
<td>Ridged</td>
<td>Removed</td>
</tr>
<tr>
<td>TRS</td>
<td>Ridge-splitting</td>
<td>Tractor-powered ridge splitting (100)</td>
<td>Ridged</td>
<td>Removed</td>
</tr>
<tr>
<td>TDR</td>
<td>Disc harrowing</td>
<td>Tractor-powered disc harrowing (70)</td>
<td>Ridged</td>
<td>Incorporated</td>
</tr>
<tr>
<td>TDP</td>
<td>Disc ploughing</td>
<td>Tractor-powered disc ploughing (150)</td>
<td>Ridged</td>
<td>Incorporated</td>
</tr>
<tr>
<td>TMB</td>
<td>Mouldboard ploughing</td>
<td>Tractor-powered mouldboard ploughing (150)</td>
<td>Ridged</td>
<td>Incorporated</td>
</tr>
<tr>
<td>TDF</td>
<td>Disc harrowing</td>
<td>Tractor-powered disc harrowing (70)</td>
<td>Flat</td>
<td>Incorporated</td>
</tr>
<tr>
<td>TSB</td>
<td>Subsoiling</td>
<td>Tractor-powered subsoiling (300) and disc ploughing (150)</td>
<td>Flat</td>
<td>Incorporated</td>
</tr>
<tr>
<td>ZRT</td>
<td>Zero tillage</td>
<td>Herbicide application</td>
<td>Flat</td>
<td>Retained as mulch</td>
</tr>
</tbody>
</table>

The design comprised two 3 x 3 balanced lattices each containing four replicates of the nine tillage treatments. Maize (Zea mays) was grown on all eight replicates in Years 1 and 2, but subsequently maize and cotton (Gossypium hirsutum) were rotated on four replicates each. The crops were sown simultaneously in June as soon as all the tillage treatments were complete. MAN, OXT and TRS plots were sown by hand while the rest were drilled with a tractor. Ridge height was about 100mm after consolidation had occurred. Row spacing was 750 mm except in the MAN system where the ridges were 900mm apart. Plant populations were about 40,000/ha.

N and P fertilisers were applied at the rates recommended by the local extension service: 65 kg N and 18 kg P/ha for maize and 32 kg N and 9 kg P/ha for cotton. Weeding was by manual hoeing at about 4 and 8 weeks after sowing except on ZRT plots where pre-emergence herbicides were
followed by pulling or cutting at ground level. After harvest, dry maize plants were either removed or left for subsequent incorporation or mulching (Table 1). Cotton plants were removed.

Soil bulk density was obtained from 100 ml cores taken in mid growing season. Infiltration was measured with double ring infiltrometers centred on or between the rows (Aremu 1979). Apparent weed cover just before weeding was scored 0 to 10. Crop yields were calculated as maize grain at zero moisture and seed cotton as picked. In Year 3, the time and power requirements of primary + secondary tillage + planting in the tractor-powered systems were recorded with a meter made by Ir. G.D. Vermeulen.

RESULTS

Soil bulk density (Figure 1) was distinctly lower at 0-60 mm within the row, particularly in the six ridged systems (MAN to TMB). Changes deeper within the row and in the inter-row were generally smaller. The compaction at 200-260mm below the ridges on TDP and TMB plots was probably caused by ploughing, while secondary cultivations caused the compaction at 100-160mm on TDF and TSB plots. Soil washed down from the ridge helped to increase bulk density at the inter-row on ridged plots while the maize residue mulch had the opposite effect on ZRT plots.

Infiltration rates varied very widely and were therefore transformed logarithmically before calculating means and standard errors (Figure 2). In most cases an equilibrium was reached by the fourth hour. Manual tillage slightly increased infiltration as compared with zero tillage, even though the latter had the advantage of a maize residue mulch. Ox tillage and all forms of tractor-powered tillage reduced infiltration.

Intensive primary and secondary tillage suppressed subsequent weed growth (Figure 3). Manual and zero tillage achieved poor control while mouldboard ploughing achieved the best. For maize, all-over tractor-powered tillage gave the best yields (Figure 3). In contrast, manual and ox-powered ridge splitting were superior to all other systems for cotton. In terms of energy and time per unit of yield produced (Figure 4), the TMB and TSB systems were about 2.5 times more costly than TRS and TDF.

DISCUSSION

Except within the ridges, the loosening produced by cultivation was short-lived. The soil is structurally weak and appears to become reconsolidated when wet simply under its own weight. Below tillage depth, there were some small increases in bulk density but when rooting was examined, no obvious impediments were found. Figure 1 suggests that incipient plough pan formation in TDP and TMB was averted by subsoiling in the TSB system.

Reduced infiltration was to some extent linked to lower porosity resulting from increased soil bulk density. Thus fourth hour infiltration rates under tractor-powered tillage were only 0.1 to 0.4 times the rate under manual tillage. However, destruction of transmitting channels due to intensive disturbance was probably more significant than the reduction in total porosity. Thus infiltration remained high under zero tillage.
Figure 1. Average soil bulk density over Years 2–6 at three depths in crop rows and one depth between rows. Dotted lines indicate bulk density at start of experiment.

Figure 2. Average infiltration rates in crop row and inter-row over Years 2 and 3. Shaded and unshaded bars show 4th and 1st hour rates respectively.
Figure 3. Average weediness in growing season and average final yield of maize and cotton over Years 3–6.

Figure 4. Energy and time requirements of primary + secondary tillage + planting per unit of crop yield for tractor-powered systems in Year 3.
The linear regression equations for crop yield $Y$ (t/ha) versus total volume $X$ (m$^3$/ha) of soil disturbed by primary and secondary tillage were:

Maize: $Y = 2.210 + 0.163X$ \hspace{1cm} r = 0.68 \text{ significant at } P = 0.05

Cotton: $Y = 1.400 - 0.014X$ \hspace{1cm} \text{correlation not significant}

Tractor-powered tillage allowed maize residues to be incorporated. At the sub-optimal (albeit recommended) fertiliser rates used, additional nutrients from decomposing residues would have assisted crop growth. For maize, this could account for the positive effect of soil disturbance on yield. For cotton, any nutritional advantage may have been offset by the adverse effects of intensive tillage on the soil.

No system was clearly the best. Manual and ox tillage systems were good for soil conditions, poor for weed control and better for cotton than for maize. The tractor-powered systems had a more degrading effect on soil conditions but weed control was better and maize yields were enhanced probably due to the incorporation of crop residues. The zero tillage system cannot be recommended unless it can control weeds better either through improved use of herbicides or by the use of more mulch. Tractor power for tillage is expensive and not widely available in northern Nigeria. Where it is available, it should not be used to perform unnecessary soil disturbance. Thus quick, shallow primary operations such as ridge splitting and disc harrowing deserve careful consideration.

CONCLUSIONS

1. In central northern Nigeria, manual and ox-powered ridge splitting and zero tillage damage soil structure less than tractor-powered systems, but provide poorer weed control.

2. The effects of tillage systems on soil conditions are not reflected consistently in crop yields.

3. Incorporation of bulky crop residues is a major advantage conferred by tractor-powered tillage.

4. In order to use tractor power efficiently, shallow primary operations such as ridge splitting and disc harrowing are appropriate.

REFERENCES


EFFECT OF THE PARAPLOW ON SOIL PROPERTIES AND PLANT PERFORMANCE

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ABSTRACT

In 1982 two field experiments were started on loess-derived soils with three tillage systems: 1. "conventional" with mouldboard plow, every year, 25-28 cm deep, 2. "reduced" with rotary harrow for seedbed preparation, every year, 5 cm deep, 3. "rational" with rotary harrow, every year, 5 cm deep, and with "Paraplow", 30-35 cm deep, every second year, i.e. 1982, 84, 86. On these well-drained, fertile soils, yields did not differ significantly. But as compared to both the other treatments, the "Paraplow" alleviated soil compaction zones, increased temperature in the seeding zone, promoted root growth and water infiltration and preserved biopores. Dehydrogenase activity and aggregate stability were highest in the top layer after "Paraplow". Suggestions are concluded, under which site conditions the "Paraplow" may stimulate reduced tillage systems.

INTRODUCTION

In Germany like in other European countries mouldboard plowing is still the dominating tillage system, leaving the soil surface bare without any plant residues, thus facilitating secondary tillage procedures. A system immanent drawback of "loose soil crop husbandry" (van Ouwerkerk, 1974) is the possibility of excessive compaction during plowing (plow soles) or of extreme surface layer recompaction, caused by the load of heavy machinery during seedbed preparation, plant cultivation and harvest. On the other side any form of "firm soil husbandry" (van Ouwerkerk, 1974), induced by a system of sequential minimum tillage or zero-tillage, leaving mulch at and near the soil surface, may lower the risk of dramatic recompaction and erosion, especially when the firm soil will develop special structural characteristics like fissures, cracks or biopores that will sustain the transmission properties of the soil with respect to water, air and rooting. The use of the "Paraplow", a "slant legged soil loosener", introduced by Howard Rotavater Company begin of the 80's, may support the build-up of a vertical, continuous system of cracks in soils (Pidgeon, 1982), thus facilitating the adoption of energy, labor and time saving minimum tillage systems (Cannell, 1985). In this paper we will report on the effect of the "Paraplow" on soil properties and on the yield performance of crops.

METHODS

The experiment started in the early fall of 1982 on loess-derived siltloams at two sites, "Garte-Nord" and "Rode". "Rational" tillage ("Paraplow") is compared with "conventional" tillage (mouldboard plow) and "reduced" tillage (rotary harrow only) (Table I). Tillage treatments were replicated four times. Straw was removed after harvest. On all the three tillage systems seedbed was prepared by use of the rotary harrow. Crop husbandry measures were performed as recommended or necessary.
Table I: Tillage treatments

<table>
<thead>
<tr>
<th>Implement</th>
<th>Depth of tillage (cm)</th>
<th>Frequency of tillage</th>
<th>Abbreviation of tillage system</th>
<th>Characteristics of tillage system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mouldboard plow</td>
<td>25-28</td>
<td>every year</td>
<td>Conventional (CON)</td>
<td>loose soil, no mulch</td>
</tr>
<tr>
<td>Rotary harrow</td>
<td>5</td>
<td>every year</td>
<td>Reduced (RED)</td>
<td>firm soil, with mulch</td>
</tr>
<tr>
<td>Paraplow</td>
<td>30-35</td>
<td>every 2. year, i.e.1982,84,86*</td>
<td>Rational (RAT)</td>
<td>loose soil, with mulch</td>
</tr>
</tbody>
</table>

*) in the years in between just rotary harrow for seedbed preparation

Soil properties were investigated at the side "Garte-Nord", restricting to one or two plot replications because of soil destruction. In 1985 under winter wheat the following properties were measured: (1) Bulk density (100 ml cores); (2) penetration resistance (penetrograph); (3) water content (auger samples); (4) soil temperature (electrical resistance thermometers); (5) total number of biopores; (6) surface connected biopores (Gypsum infil- tration method after Fitzpatrick et al., 1985); (7) aggregate stability (change of mean-weight diameter after wet-sieving as compared to dry-sieving, AMWD; Hartge, 1974); (8) microbial activity (dehydrogenase activity by colorimetric determination of 2,3,5-triphenyl formazan; Thalmann, 1968); and (9) rooting density (profile wall method). In 1987 water infiltration was measured with a rainfall simulator. The 1-m²-soil surface was either protected from aggregate breakdown and slaking using four layers of plastic gauze or was left unprotected.

RESULTS AND DISCUSSION

Conventional tillage (CON) caused a distinct plow sole compaction in 30-40 cm depth, whereas rational tillage (RAT) with the "Paraplow" had eliminated this compaction zone (Fig.1). RAT and reduced tillage (RED) exhibited a layer of relatively high bulk density and penetration resistance in 5-20 cm depth, probably caused by the rotary harrow and more in the case of RED by traffic.

![Graph showing bulk density and penetration resistance](image1)

Fig.1: Profiles of bulk density and penetration resistance with three tillage systems.
At beginning of May RED was highest in water content as compared to the other tillage systems (Fig.2). After a dry spell at beginning of June water content was lowest in the profile of CON and highest near the soil surface of RAT. After receiving some 60 mm of rainfall in June water seemed to have infiltrated deeper into the profile at 19 June, when loosened by "Paraplow" (RAT), whereas water content was again highest in the surface 0-10 cm layer of RED like in May.

![Soil moisture content profiles at three dates with three tillage systems.](image)

Water filled pore space (WFP), which relates volumetric water content to total porosity, influences strongly microbial activity, being highest for aerobes at 60% WFP (Linn and Doran, 1984). WFP was calculated for 9 May (Fig.2), assuming that water content was near field capacity. As compared to the other tillage treatments, RAT reduced WFP significantly (Fig.3). It was highest in the plow sole layer of CON.

![Profiles of water filled pore space near field capacity as affected by three tillage systems.](image)

Soil temperatures increased during the day more on RED and RAT as compared to CON (Fig.4). Higher temperatures were recorded down to 15 cm depth. Not only during the day but also during the cooling period of the night until the early morning hours the conventionally tilled soil showed always lower temperatures. This unexpected result may be explained by differences in the albedo, being highest after surface slaking and surface seal drying with CON.

Biopores, built up by earthworms, covered the largest area in the top soil of CON during May (Fig.5). This is true for the total number of channels (0-15 cm) and for those, which exhibited a continuous surface connection (0-25 cm). During June until August not only the total number, but still more drastically the number of surface-open biopores was reduced in the plowed soil. At 6 August CON did not reveal any more a "short-circuit" connection between surface and subsoil by biopores. This link was preserved the most by RED.
Soil temperature (°C)

Fig. 4: Soil temperature profiles in the morning and at noon with three tillage systems.

Earthworm channels 1-8 mm φ (% of area)

Fig. 5: Percentage area of total and surface connected biopores built by earthworms at three dates as affected by the tillage system.

Metabolic activity of soil microorganisms was higher in the top 10-cm layer of RED and RAT as compared to CON (Fig. 6, top), a response that may be explained by the organic matter content, being lowest in CON (Fig. 6, top right) and by the soil temperature profiles (Fig. 4). Activity was always highest in the 0-10 cm layer of RAT and lowest in the 10-20 cm layer of RED with a minimum of WFP (Fig. 3). Low enzyme activity in the 0-10 cm layer of CON is paralleled with low aggregate stability, i.e., a high change in mean-weight diameter (Fig. 6). With the "Paraplow" always highest stability was induced down to 10-20 cm depth as compared to RED and CON.

When the soil surface was protected by plastic gauze infiltration rate stayed highest with RAT (Fig. 7). After removal of the artificial protection cover infiltration rate dropped nearly to zero with CON after two hours of heavy irrigation (160-170 cm day⁻¹) but remained near 20 cm day⁻¹ with RAT and RED. This higher infiltration rate of RAT and RED may be explained by aggregate stability (Fig. 6), biopore surface connection (Fig. 5) and organic mulch residues, left at the soil surface (Fig. 7).

After "Paraplow" rooting density of wheat was increased almost throughout the soil profile as compared to the other two tillage systems (not shown). Within the pre-boot stage (30 May) total root length amounted to: CON: 3.6; RED: 3.5 and RAT: 5.0 km · m⁻² surface.

There was a tendency of yield increase in the years subsequent to the "Paraplow" treatment, but altogether yield differences between tillage systems were not significant (Table II).
Dehydrogenase activity (mg Triphenyl-formazan g⁻¹ soil) vs Corg (%)

![Graphs showing enzyme activity, organic carbon content, and change in mean-weight diameter of aggregates (AWD) as a function of soil depth with three tillage systems at three dates.](image)

Fig. 6: Enzyme activity, organic carbon content and change in mean-weight diameter of aggregates (AWD) as a function of soil depth with three tillage systems at three dates.

![Infiltration into artificially protected and unprotected soil as affected by three tillage systems.](image)

Fig. 7: Infiltration into artificially protected and unprotected soil as affected by three tillage systems. The coverage with organic mulch residues is indicated.

Table II: Effect of "Paraplow" treatment on crop yield in 2 long-term field experiments with reduced tillage intensity on loessial soils near Goettingen. (Grain yield with 86% d.m.; sugarbeet yield: purified sugar; differences between means (n = 4; α = 0.05) : n.s.)

<table>
<thead>
<tr>
<th>Location</th>
<th>Year</th>
<th>Crop</th>
<th>Tillage treatment</th>
<th>CON</th>
<th>RED</th>
<th>RAT</th>
</tr>
</thead>
<tbody>
<tr>
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<td></td>
<td></td>
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<td>t ha⁻¹</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Garte Nord</td>
<td>1983</td>
<td>Winter rye</td>
<td></td>
<td>5.10</td>
<td>5.42</td>
<td>5.62</td>
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<tr>
<td></td>
<td>1984</td>
<td>Oats</td>
<td></td>
<td>5.90</td>
<td>5.61</td>
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<tr>
<td></td>
<td>1985</td>
<td>Winter wheat</td>
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<td>6.79</td>
<td>7.24</td>
<td>7.04</td>
</tr>
<tr>
<td></td>
<td>1986</td>
<td>Winter barley</td>
<td></td>
<td>4.64</td>
<td>4.91</td>
<td>4.90</td>
</tr>
<tr>
<td></td>
<td>1987</td>
<td>Sugar beet</td>
<td></td>
<td>8.44</td>
<td>8.20</td>
<td>8.43</td>
</tr>
<tr>
<td>Rode</td>
<td>1983</td>
<td>Faba beans</td>
<td></td>
<td>3.89</td>
<td>4.05</td>
<td>4.24</td>
</tr>
<tr>
<td></td>
<td>1984</td>
<td>Oats</td>
<td></td>
<td>4.63</td>
<td>4.77</td>
<td>4.54</td>
</tr>
<tr>
<td></td>
<td>1985</td>
<td>Winter wheat</td>
<td></td>
<td>6.48</td>
<td>6.47</td>
<td>6.66</td>
</tr>
</tbody>
</table>

1) CON: mouldboard plow; RED: rotary harrow only; RAT: "Paraplow"

2) Treatment RAT in autumn of 1982, 1984 and 1986
CONCLUSION

The "Paraplow" improved the biological and physical properties of a loessial soil. However, yield responses in two field experiments on well-drained, fertile soils were insignificant. The "Paraplow" may facilitate the acceptance of erosion-controlling reduced tillage systems on compacting soils with low biological activity, as vertical cracks and fissures may improve the transmission and rooting properties of the soil. On soils of low structural stability, susceptible to compaction, partially water-logged, a yield increase might be expected (Davies et al., 1982; Braim et al., 1984) by the beneficial effects of the "Paraplow" on yield limiting soil properties.

ACKNOWLEDGEMENT

We are grateful to Mrs. A.-E. Seevers and Messrs. K. Nieth, D. Scharenberg and O. Wendroth for their assistance in collecting and processing data on soil and rooting properties. We thank Mrs. G. Kolb for preparing the graphs and for typing the text.

REFERENCES


DIRECT PLANTING OF POTATOES

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SUMMARY

Direct planting with no prior tillage was investigated in 23 trials over the years 1978 to 1987. Ridging equipment was used after planting in the early trials to give satisfactory covering of the setts. Tines mounted on a combine fertilizer/planting machine were later found to give sufficient loose soil without separate ridging. Direct planting gave on average the same yield as traditional plough tillage. The latter method gave lower yields in dry years and higher yields in wet years than direct planting. Direct planting resulted in more coarse soil aggregates, higher soil moisture contents and lower soil temperature. This caused delayed development and maturation, with lower dry matter concentrations and a greater proportion of large tubers in late varieties. The growth period of early varieties was extended by direct planting, leading to greater yield than with traditional tillage when lifted late. Little evidence was found of tuber exposure to light (green colouring) in either tillage method.

INTRODUCTION

Traditional tillage for potato-growing in Norway comprises autumn ploughing followed by 2-3 relatively deep tine cultivations in spring. Results are presented here of comparisons between direct planting and traditional tillage over the years 1978 to 1987.

METHODS AND MATERIAL

The trials were performed on stony moranic loam soil, usually following cereal crops. Straw residues were either removed or burnt. In the first five trial years, fertilizer was surface applied, and the potatoes were planted with a 2-row machine with a disc-ridging attachment. This left the setts uncovered in untilled soil, and necessitated two passes with ridge equipment to give a satisfactory result. In the next four years, a combine fertilizer/planting machine with mouldboard-ridger was used, but this also gave unsatisfactory covering. In the final year, two tines in each furrow were attached to this machine to give enough loose soil for ridging.

A fertilizer rate of 100 kg N per hectare was used, in an NPK-compound. Pre-emergence weed-killer was used. Hand-hoeing was performed in some cases. Spraying against blight was carried out when required.
RESULTS

Direct planting resulted in higher soil moisture contents throughout the season than traditional tillage. The moisture content in the drill at lifting was, on average for two trials, 21.4% (w/w) with traditional tillage and 25.1% with direct planting (P<0.001). This can cause lower soil temperature with the latter method. A difference of 0.2°C was found in one trial in 1987 over the period 24/6 to 17/7.

Traditional tillage gave a higher proportion of small soil aggregates than direct planting. On average for two trials, the content of aggregates smaller than 5 mm was 65% with the former and 49% with the latter (P<0.001).

Both the potato setts and the new tubers were located higher in the ridge with direct planting than with traditional tillage. The mean tuber depth from the top of the ridge was 8.7 cm for the former and 11.4 cm for the latter method. Little greening of tubers was found in these trials, and there was no difference between the tillage methods.

The average yield of 20 trials was identical for both tillage treatments (table I). There was a tendency toward higher dry matter concentrations with traditional tillage than with direct planting. The latter method gave a greater proportion of large tubers and fewer medium sized tubers.

Table I. Tuber yield, dry matter contents and tuber size distribution, on average for 20 trials in 1978-87. Varieties: 'Pimpernel' (7), 'Kerrs Pink' (6), 'Mandel' (3), 'Laila' (2), 'Saturna' (1), 'Troll' (1).

<table>
<thead>
<tr>
<th>Tillage treatment</th>
<th>Yield t/ha</th>
<th>DM %</th>
<th>&gt;45mm</th>
<th>45-35mm</th>
<th>&lt;35mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct planting</td>
<td>23.8</td>
<td>24.9</td>
<td>63</td>
<td>30</td>
<td>7</td>
</tr>
<tr>
<td>Traditional</td>
<td>23.9</td>
<td>25.1</td>
<td>61</td>
<td>32</td>
<td>7</td>
</tr>
</tbody>
</table>

n.s. n.s. P<0.05 P<0.05 n.s.

Direct planting gave higher yield in dry years than traditional tillage, whilst the opposite was true in wet years (figure I). This may be explained in terms of soil moisture content/soil aeration/soil temperature.

Potatoes were grown in 1987 in a long-term trial with various autumn cultivations. The trial was established in 1976, and this was the second potato crop grown since then. No spring tillage was performed in 1987. Both stubble cultivation and autumn ploughing resulted in lower tuber yields than the no-tillage treatment (table II). Dry matter
concentrations increased with increasing autumn tillage, in a similar manner as found for spring tillage. Tuber size distribution was also affected in a similar way as in other trials, with an increasing proportion of large tubers for treatments with low tillage intensity.

Table II. Tuber yield, dry matter contents and tuber size distribution for direct planting after various autumn cultivations. Result for variety 'Pimpernel' in 1987, in a long-term trial established in 1976.

<table>
<thead>
<tr>
<th>Autumn cultivation:</th>
<th>Tuber, t/ha</th>
<th>DM, %</th>
<th>Over 45mm, %</th>
<th>45-35 mm, %</th>
<th>Under 35 mm, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stubble cultivation:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ploughing</td>
<td>Without</td>
<td>With</td>
<td>Without</td>
<td>With</td>
<td>LSD,5%</td>
</tr>
<tr>
<td></td>
<td>Without</td>
<td>Without</td>
<td>With</td>
<td>With</td>
<td></td>
</tr>
<tr>
<td>Tuber, t/ha</td>
<td>26.8</td>
<td>26.2</td>
<td>25.7</td>
<td>23.0</td>
<td>3.6</td>
</tr>
<tr>
<td>DM, %</td>
<td>26.3</td>
<td>26.8</td>
<td>26.9</td>
<td>27.2</td>
<td>1.2</td>
</tr>
<tr>
<td>Over 45mm, %</td>
<td>67</td>
<td>57</td>
<td>53</td>
<td>50</td>
<td>8</td>
</tr>
<tr>
<td>45-35 mm, %</td>
<td>26</td>
<td>32</td>
<td>35</td>
<td>37</td>
<td>5</td>
</tr>
<tr>
<td>Under 35 mm, %</td>
<td>7</td>
<td>11</td>
<td>12</td>
<td>13</td>
<td>3</td>
</tr>
</tbody>
</table>

A further trial in 1987 resulted in little difference in yield between direct planting and harrowing (table III), but marked differences between tillage treatments in the number of tubers and in tuber size distribution. Direct planting gave fewer and larger tubers than harrowing.
Table III. Some yield components with two tillage systems. One trial with variety 'Kerrs Pink' in 1987.

<table>
<thead>
<tr>
<th>Tillage</th>
<th>None</th>
<th>Harrowed</th>
<th>Signif.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tuber yield, t/ha</td>
<td>25.0</td>
<td>24.6</td>
<td>n.s.</td>
</tr>
<tr>
<td>Over 45 mm, %</td>
<td>69</td>
<td>63</td>
<td>P&lt;0.05</td>
</tr>
<tr>
<td>45-35 mm, %</td>
<td>26</td>
<td>32</td>
<td>P&lt;0.05</td>
</tr>
<tr>
<td>Mean weight of tubers &gt;45 mm (g)</td>
<td>109</td>
<td>94</td>
<td>P&lt;0.01</td>
</tr>
<tr>
<td>Mean tuber weight (g)</td>
<td>65</td>
<td>60</td>
<td>P&lt;0.05</td>
</tr>
<tr>
<td>No. of tubers per plant</td>
<td>8.7</td>
<td>9.3</td>
<td>P&lt;0.05</td>
</tr>
</tbody>
</table>

In a third trial in 1987, differences were found between tillage treatments in the rates of development and maturation of two early varieties, 'Laila' and 'Mandel' (table IV). Early lifting of 'Laila' on the 28th August revealed 11% higher yield with traditional tillage than with direct planting. However, the foliage remained green longer for the latter treatment than for the traditional tillage treatment, resulting in higher yield with direct planting a month later. The yield of 'Mandel' harvested 20th September was 11% higher with direct planting than with traditional tillage. The reason for this effect in early varieties is thought to be due to differences in soil temperature between tillage treatments. The growing season in Norway is too short for such compensation in late varieties.

Table IV. Tuber yield and dry matter concentrations for two tillage systems at three harvest dates for the early variety 'Laila'.

<table>
<thead>
<tr>
<th>Harvest date</th>
<th>Tuber yield Direct planting t/ha</th>
<th>Rel. %</th>
<th>Dry matter Direct planting %</th>
<th>Trad. planting %</th>
<th>diff.</th>
</tr>
</thead>
<tbody>
<tr>
<td>28th August</td>
<td>28.9</td>
<td>111</td>
<td>19.4</td>
<td>19.4</td>
<td>+0.8</td>
</tr>
<tr>
<td>10th September</td>
<td>36.9</td>
<td>100</td>
<td>20.3</td>
<td>20.3</td>
<td>+0.8</td>
</tr>
<tr>
<td>28th September</td>
<td>38.8</td>
<td>92</td>
<td>20.7</td>
<td>20.7</td>
<td>0</td>
</tr>
</tbody>
</table>

DISCUSSION

It is cheaper and easier to achieve direct planting of potatoes than direct drilling of cereals. The latter requires the use of expensive, specially-designed seed-drills, whilst the former is possible using conventional combine fertilizer/planting machines. A simple modification of such machines gives satisfactory ridge shape. Weed control may be performed
by a variety of means - chemical, mechanical, hand-weeding, or a combination of these. Direct planting allows tubers to grow in uncompacted soil, which is an advantage.

The growth, development and maturation of potatoes grown in this way may be delayed due to coarser soil structure, moister soil and lower soil temperature. Late varieties will have lower dry matter concentrations and lower yields in cold wet seasons, whilst early varieties will have an extended growing season, and higher yields if lifted late. All varieties will have higher yields with direct planting in warm, dry seasons, due to better water supply.

Direct planting gives fewer but larger tubers than traditional spring tillage. Autumn tillage was also found to increase tuber initiation. At present, it is thought that differences in soil physical properties between the tillage systems, are responsible for this finding.
OPTIMISING RAINFALL UTILISATION IN SOUTHERN QUEENSLAND, AUSTRALIA

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2 Queensland Department of Primary Industries, Roma, (Australia)
3 Queensland Department of Primary Industries, Toowoomba, 4350 (Australia)

ABSTRACT

Moisture stress almost always limits yields in southern Queensland. Alternative crop-tillage systems are being examined through a) monitoring runoff from small catchments, b) rainfall simulation studies, and c) computer simulation of crop yields. Stubble and tillage management for increased water storage and planting date to avoid frost at anthesis were important for optimum soil and water conservation and crop yield, but gypsum had no effect on this soil.

INTRODUCTION

Low and unreliable rainfall in the western part of the southern Queensland produce erratic crop yields and uncertain economic returns. This region, known as the Maranoa, experiences high intensity summer storms resulting in severe erosion which threatens the production base of the region. Runoff also represents a loss in 'effective' rainfall.

Wheat is grown in the winter months using some winter rainfall and moisture stored during a summer fallow. Rainfall is summer dominant but evaporation during the summer is also large. Wheat yields are limited by three major factors: unreliable planting rainfall, moisture stress around anthesis and frost risk at anthesis. Coincidence of the optimum anthesis date for efficient water use with a high frost risk period means that yields are usually limited by either moisture stress or frost. The role of fallow and crop management is to reduce these limitations by maximising soil water storage and adjusting planting dates according to varietal phenology and rainfall distribution. Since rainfall is highly variable, extended experimentation would be needed to measure the interactions between variety, planting date and seasonal conditions.

A computer model which predicts wheat yield (Woodruff, 1986) was used to examine the expected effect of tillage management and planting date on yield probability.

Catchment studies 300 km to the east in a more favourable climate, have shown that tillage systems which maintain crop residue significantly reduce runoff and erosion and increase wheat yields (Freebairn and Wockner 1986, Freebairn et al 1986). A study was established in 1982 to investigate the influence of tillage on water balance and erosion in the drier western region. Some early results of this study led to simulated rainfall being used to examine the effects of gypsum in ameliorating hard setting and surface sealing of the soil on the catchments. This paper discusses results from the catchment study, a simulated rainfall study, and a computer simulation of wheat production.
MATERIALS AND METHODS

Catchment study

This study was conducted at 'Fairlands', 10 km NW of Wallumbilla (26° 28'S, 149° 06'E). The soil, a brown clay derived from Cretaceous sediments (mudstone), is weakly to moderately hard-setting and exhibits some cracking when dry. The soil supported brigalow (Acacia harpophylla) and belah (Casuarina cristata) vegetation prior to clearing in 1963 and has been cropped continuously since 1966. Salts are concentrated at 40-50 cm, and 80% of potential plant available water (10 cm) is held in the surface 60 cm.

Rainfall is summer dominant (68% October - March inclusive) and characterised by intense convective storms and long dry periods. Mean annual rainfall is 587 mm with 54 wet days. The coefficient of variation of monthly rainfall ranges from 85% in the summer to 110% for the winter months. Annual pan evaporation is 2700 mm with daily mean values greater than 10 mm from November to February. Mean annual rainfall during the 5 year experiment period was similar to the long term average, with one very wet year (845 mm) and two very dry years (468 and 376 mm).

Four catchments, delineated by graded banks and channels, discharge runoff through 1.216 m wide Cipoletti weirs. Catchment areas are 2.4-5.9 ha and landslope is 1.5-3%. The channel leading to each weir is at 0.3% slope. Water level is recorded by direct-height float recorders and samples of runoff water are collected by rising stage sediment samplers.

At the beginning, end and several intermediate times, soil moisture is measured gravimetrically to a depth of 1.5 m at nine locations in each catchment. Yields were determined by harvesting grain from three 7 m by 400 m quadrats from each catchment.

Treatments were applied to each catchment after wheat harvest in December each year to provide a range of surface conditions. For the first three summer fallow periods (1982/83 - 1984/85) the treatments were;

- **minimum tillage;** limited chisel ploughing or scarifier with use of herbicides to control weeds.
- **blade tillage;** weed control using a 1.8 m blade plough and final cultivation with a scarifier before planting.
- **chisel tillage;** weed control using a chisel plough to reduce crop residue levels quickly after harvest.
- **chisel or blade tillage + 5 t ha⁻¹ gypsum;** this treatment was applied in December 1985 to determine if gypsum could improve infiltration.

For the last fallow period (1986/87), the chisel tillage treatment included burning to further reduce crop residue.

Simulated rainfall study

A rotating disc rainfall simulator (Morin et al 1967) applied rainfall to trays of soil 0.25m wide, 0.4 m long and 0.10 m deep. A factorial design was used; two crop cover levels (bare and 80% cover of wheat stubble; C- and C+), three rates of gypsum (0, 2 and 5 t ha⁻¹; G0, G2 and G5) and four replicates. Rainfall was applied three times, each for 20 minutes at 108 mm h⁻¹; a) initial run on soil sieved to pass a 2 cm sieve, b) second run, rain applied following drying (4 days at 40 °C) after the first rain and, c) the trays without residue cover were split into
duplicates after the second rain and were either left intact or given a simulated tillage. Runoff was measured at five minute intervals and total infiltration was determined by weighing each tray before and after rainfall.

The wheat yield model

Wheat yield is closely related to (i) leaf area at anthesis which sets yield potential, and (ii) water supply, temperature and evaporative demand in a short period around anthesis. The duration of the phase from planting to flowering is very important; where this is long it results in heavy soil water depletion and hence increased chance of water stress at or after anthesis. The model used in this study considers varietal phenology and uses daily climatic inputs; it can therefore be run using long records of historical data to provide probabilistic estimates of crop yield (Hammer et al 1984, Woodruff 1986). In this paper, we only consider the influence of soil moisture at planting on yield expectations.

RESULTS AND DISCUSSION

Catchment study

Water balance and yield data are presented in Table 1. 'Minimum tillage' resulted in the most runoff in all years and 'blade tillage' the least. High runoff under minimum tillage is attributed to the rapid formation of a surface seal reflecting the hard setting nature of the soil. Tillage by blade, on the other hand, reformed surface roughness and broke any surface seal, yet maintained surface cover. Chisel tillage was intermediate between these two treatments in effect. 'In crop' runoff was due to unseasonably high autumn rainfall especially in 1983 and 1984 and differences between treatments were minor as surface conditions were similar after planting (with cultivator / drill). Differences between treatments in annual runoff were less than measured in similar experiments on self mulching soils on the eastern Darling Downs, probably due partly to soil differences but also to the lower levels of crop residue present and to low rainfall intensities at Wallumbilla. A study of the influence of gypsum on infiltration behaviour was prompted by the above result as, gypsum had improved infiltration and associated crop yield in the region (So et al 1978). However, in this experiment gypsum had little effect.

Simulated rainfall study

Simulated rainfall demonstrated potential improvement in infiltration with the addition of gypsum and/or stubble cover (Figure 1). Results (not shown) were similar when simulated rainfall was re-applied after drying. When half the uncovered plots were 'cultivated' i.e. top 5 cm inverted, there were no significant differences between ± tillage or ± 5 t ha⁻¹ gypsum when simulated rainfall was reapplied for the third time. This result is consistent with the lack of response to gypsum in the catchment study although no high intensity rainfall or large runoff events have been recorded since gypsum application. Gypsum reduced slacking of aggregates in the simulated rainfall study. This was evident by a greater proportion of particles in runoff water in the < 0.03 mm size range. When gypsum was applied, 30% of sediment in the <0.125 mm was <0.03 mm whereas on non treated soil, 90% of sediment was < 0.03 mm. As this was the only distinguishing difference resulting from gypsum application, we presume
that the < 0.03 mm size particles are responsible for surface sealing. Since the effect of gypsum appeared short lived under successive rainfall, it appears that the main action of gypsum was to temporarily increase the ionic concentration rather than replace Na⁺ with Ca²⁺ ions.

Table 1. Runoff, fallow efficiency (% fallow rainfall stored in soil) and yield from four catchments near Wallumbilla.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Minimum Blade tillage</th>
<th>Chisel tillage</th>
<th>Chisel tillage + gypsum</th>
</tr>
</thead>
<tbody>
<tr>
<td>1982-83</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fallow rainfall</td>
<td>mm 91</td>
<td>mm 56</td>
<td>mm 83</td>
</tr>
<tr>
<td>Fallow runoff</td>
<td>mm 41</td>
<td>mm 41</td>
<td>mm 46</td>
</tr>
<tr>
<td>Fallow efficiency</td>
<td>% 34</td>
<td>% 41</td>
<td>% 41</td>
</tr>
<tr>
<td>Wheat yield</td>
<td>t ha⁻¹ 1.6</td>
<td>t ha⁻¹ 1.6</td>
<td>t ha⁻¹ 1.6</td>
</tr>
<tr>
<td>1983-84</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fallow rainfall</td>
<td>mm 53</td>
<td>mm 51</td>
<td>mm 58</td>
</tr>
<tr>
<td>Fallow runoff</td>
<td>mm 88</td>
<td>mm 75</td>
<td>mm 80</td>
</tr>
<tr>
<td>Fallow efficiency</td>
<td>% 13</td>
<td>% 18</td>
<td>% 9</td>
</tr>
<tr>
<td>Wheat yield</td>
<td>t ha⁻¹ 2.1</td>
<td>t ha⁻¹ 2.6</td>
<td>t ha⁻¹ 2.2</td>
</tr>
<tr>
<td>1984-85</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fallow rainfall</td>
<td>mm 36</td>
<td>mm 16</td>
<td>mm 25-35¹</td>
</tr>
<tr>
<td>Fallow runoff</td>
<td>mm 2.3</td>
<td>mm 0</td>
<td>mm 0.9</td>
</tr>
<tr>
<td>Fallow efficiency</td>
<td>% 11</td>
<td>% 35</td>
<td>% 30</td>
</tr>
<tr>
<td>Wheat yield</td>
<td>t ha⁻¹ 1.4</td>
<td>t ha⁻¹ 2.1</td>
<td>t ha⁻¹ 1.7</td>
</tr>
<tr>
<td>1985-86</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fallow rainfall</td>
<td>mm 7</td>
<td>mm -</td>
<td>mm 8 ¹⁰²</td>
</tr>
<tr>
<td>Fallow runoff</td>
<td>mm 0</td>
<td>mm -</td>
<td>mm 0</td>
</tr>
<tr>
<td>Fallow efficiency</td>
<td>% 9</td>
<td>% -</td>
<td>% 18-21 2²</td>
</tr>
<tr>
<td>Wheat yield</td>
<td>t ha⁻¹ 1.5</td>
<td>t ha⁻¹ -</td>
<td>t ha⁻¹ 1.3</td>
</tr>
<tr>
<td>1986-87</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fallow rainfall</td>
<td>mm -</td>
<td>mm 1</td>
<td>mm 23 1⁴</td>
</tr>
<tr>
<td>Fallow runoff</td>
<td>mm -</td>
<td>mm 0</td>
<td>mm 0</td>
</tr>
<tr>
<td>Fallow efficiency</td>
<td>% -</td>
<td>% 14</td>
<td>% 22.4 2⁴</td>
</tr>
<tr>
<td>Wheat yield</td>
<td>t ha⁻¹ -</td>
<td>t ha⁻¹ fail</td>
<td>t ha⁻¹ fail</td>
</tr>
</tbody>
</table>

Notes: 1- weir failure; 2- chisel tillage; 3- stubble burnt; 4- blade tillage
Figure 1. Cumulative infiltration for six surface treatments using simulated rainfall on 'Fairlands' clay (open symbols-bare soil, closed symbols 80% stubble cover; G0, G2, G5 refer to 0, 2 and 5 t ha⁻¹ gypsum).

Model study

Simulated crop yield (disregarding frost risk) based on 100 years' of daily rainfall at Roma are presented for two planting dates and two starting soil moisture regimes in Figure 2. Frost risks associated with planting on 1 May and 15 June are 48% and nil respectively. While yield potential is higher for the earlier planting, frost risk is unacceptably high.

The influence of stored soil moisture on yield expectation is clear, an extra 50 mm of available soil water increased mean yield from 1090 to 1370 kg ha⁻¹. In all but the wettest years (5% probability), yields were predicted to be 300 kg ha⁻¹ higher. If 1000 kg ha⁻¹ covers the fixed cost of production in this environment, this yield increase can have a major influence on profitability. This analysis shows that small increases in moisture storage can have a large impact on yield and profit expectation. Also, this justifies efforts to increase water storage by modifying tillage practice or other means. By examining other planting date and variety strategies, yield goals can be predicted for a variety of scenarios.
CONCLUSIONS

1. Runoff is a significant component of the water balance in this semi-arid environment.
2. Tillage and stubble cover in conjunction can reduce runoff and improve moisture storage.
3. Gypsum appears to have little effect on infiltration into this soil.
4. For each extra mm of water stored, on average an extra 6 kg ha$^{-1}$ of grain can be produced.
5. Additional moisture storage greatly increases the probability of exceeding 1000 kg ha$^{-1}$, an arbitrary but realistic cost of production.
6. Crop models and field experimentation can be combined to assess proposed modifications to tillage/crop systems.

REFERENCES

PERFECT SOIL CULTIVATION - HEALTHY SOIL

FRANZ GEIGER

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ABSTRACT

Soil erosion is a worldwide problem is increasingly becoming serious in our immediate production area, because it causes irreparable soil loss. Single technological measures used in conventional basic tillage, in cultivation and intercultivation cannot constrain this problem sufficiently, just as little as cropping measures themselves. What we can do from the technical standpoint to reducing the erosion? There are four main points therefore:

1. Soil cultivation in the right moment
2. Avoid soil compacting (no ploughing under wet conditions etc.)
3. Soil cultivation which produced an even but rough soilsurface
4. Loosing the subsoil and tractor-wheelmarks (also from harvest combines trailers and other farm vehicles).

This short report will shown the possibilities of technical implements with which the Austrian farmers worked to avoid the soil compaction and erosion.

INTRODUCTION

In addition do dying forest another topic of discussion has recently come into the focus: the various problems regarding soil, compacting and erosion.

If the soil is working in a suitable and sensible way a substantial contribution can made to words a healthy soil. Nowadays modern soil cultivation must be regarded as a whole and not merely from the point of view of one tool. Tractor and soil cultivation equipment must seen as one unit which has a substancial influence on the quality of the soil.

The various individual measures taken to cultivate the soil have the following obvious aims:

- to preserve and improve the soil structure
- to work in the organic matter after the harvest, also organic and mineral fertilizers
- to fight weeds
- to prepare the seed bed

The task of modern soil cultivation must be to preserve a good, healthy soil structure where it is present and to restore the structure where it is damaged, to do so both technical means and correct crop farming must be used.

The condition of the bottom soil causes particular problems. These include the sole of the plough and soil compaction due to tractor movement on the field. Such compactings can often reach down as far as one meter.

Compactings produced from the wheel slip are even more dangerous than
the simple compactings caused by weight pressure because wheel slip causes a clogging of the pores in addition to the compacting. To reduce such effects the solution is to use following technical developments:

Four wheel drive tractors fitted with radial-ply tyres. This combination brings the so called "multipass effect". The result is that the soil pressure and the wheel slip are reduced.

Picture 1  Multipass-Effect

\[ Z_1 \text{ ... track depth from the propelled front wheel, soil not compacted} \]

\[ Z_2 \text{ ... track depth from the rear wheel after the pre-compacted soil from the front wheel} \]

In soil cultivation the reduction of the wheel slip results on energy saving of 3.7 l per hectare. A further development in the tyre sector are low pressure tyres such as "wide tyres" (Breitreifen) and "terra tyre\(^\text{®}\). When using such tyres to work on the field the inner tyre pressure can be reduced to 0.8 bar or 0.4 bar compared with 1.2 bar of the traditional tyre, by so doing the specific wheel pressure to the soil is substantially reduced.

The multi-pass effect occurs in the following way: In the course of a pass the front-drive axle makes the soil firmer \((Z_1)\) the rear-drive axle turns its wheels over a prepared soil and needs only \((Z_2)\) for a better tyre grip. Thus the slip is reduced, fuel is saved and the engine power is more efficiently used.
The first step necessary to improve the soil is to get rid of soil compaction, if possible with the aid of the tractor and tyre concept described above. Improvement of compacting soil means changing the soil structure from dense to loose. From samples of many soil profiles we know, that soil compaction to work on the soil and wheel pressure as a rule lie between 45 and 60 cm (average) deep, the maximum goes down to 1 meter. In order to break down such soil compaction earth loosening equipment, the so called subsoilers, must be used which can dig underneath this compacting soil zone to achieve the optimal loosening effect.

The last results are achieved with the heavy-deep cultivator or subsoiler. These can work underneath the compaction and loosening them down. When it is necessary we must repeated the work by changing of the working direction of the cultivator or subsoiler a large acreage of compacted soil can be broken down and loosened within a comparatively short space of time. Hubschwenk-(stroke-swing-), Wippschar-(wag share, or lifting blade-), and Stechhubblockerer (plunge stroke - subsoiler) are kinds of deep cultivators which can be used for large-scale loosening work.
Soil cultivation is in a state of change, it is developing at the moment from reduced, conserving cultivation towards minimum tillage. By reducing the number of operations while working the soil the vehicle tracks on the field are reduced and the soil compaction kept to a lower rate.

Conservation tillage with the aid of the cultivatore or rotating working tools leaves a rough but an even soil surface interspersed with organic matter which also reduces wind and water erosion.

The next development is in the direction of minimal tillage. The aim is to work and till the soil in one operation. The great change in outlook in soil cultivation with the aim of preventing soil erosion and soil compacting has been to do away with the idea of "sweeping clean" ("clean table"), i.e. no growth should be seen after the soil has been worked. Nowadays farmers aim to achieve a rough surface soil in order to prevent erosion.

Erosion is usually caused by too finely worked soil and by the arable surface having been left open for a to long time. This soil is especially vulnerable in spring to erosion by wind and water. When it rains the force of the falling raindrops causes particles to be loosened out of the close-knit structure of the soil. This causes usual and when this dries a crust forms which prevents further rain penetrating the surface. This is the most frequent cause of erosion by surface water. Thus the soil surface must be kept rough and mixed with the organic matter to prevent this happening.

During the summer of 1986 we have had a particular experience in Austria due to a series of thunderstorms after harvest. On fields where the straw had been burned the surface soil had become loose and open. The wash of the very heavy rainfall caused severe soil erosion.
In contrast, neighbouring fields on which the straw had not been burned but baled and removed and the stubble worked in using a scuffer or cultivator to make a rough surface, there was no soil loss caused by heavy rainfall.

Compacted soil is easily recognised after a rainfall. The water fails to soak the soil and lies in pools. This situation has to be remedied using a sub-soiler to break the compaction which should be used at a depth of at least 60 cm or more. However, this operation can be achieved successfully only under dry conditions. With the soil so loosened we obtain good water and air circulation.

**Picture 4** Influence of steepness and length of slope on the annual erosion

The three fundamentals of soil fertility can be described as mechanical, chemical and biological. The mechanical-physical aspekt is in order when the soil is firm yet easy to till. The chemical state is the asorption of enough nutrients to be delivered phase by phase to the roots of the plants. The soil is in good health biologically when the transformation of organic matter takes place slowly and without disturbance.

With the help of modern soil cultivation practice these three aspects are achieved. To maintain the soil in good condition it is important to reduce both compression from the weight of the tractor and wheelslip. The 4-wheel drive tractor on high volume tyres enables us to do this. Coupled with the reversible plough it is very easy to make a good level seedbed without the need to make crowns and finishes.

From the following figures it is claimed that the efficiency of a reversible plough is higher than that of a mouldboard plough:
Phaeacia halts erosion

Soil erosion is an increasingly serious problem world-wide particularly in corn and sugar beet growing areas, where wind and water have their influence in relation to the steepness of the field in which some areas can be drastic as is illustrated in the diagram.

One method of controlling erosion is to plough a heavy winter furrow or use a heavy cultivator to make a rough surface and also retain organic matter on the soil surface. In Austria we sow on the rough surface the phaeacia plant. For seeding in this organic matter we can use the following methods:

Two step system -
- first plough, then harrow to produce the rough surface,
- next sow the phaeacia using a single seeder drill.

One step system -
- by this method the cultivation and the drilling are done at the same time in one pass over the field using a combined plough/cultivator and drill.

The phaeacia seeds germinate, grow quickly into flourishing plants bearing a dark blue blossom. Since the plant is not resistant to frost it quickly collapses to form a protective layer over the soil. Thus the soil is shielded from the worst ravages of wind and water erosion. In spring time all that is necessary is a stroke with the harrow to make a seed bed and follow with the seed drill. Alternatively, instead of harrowing the whole field one can use a rotary tiller to make 25 cm wide seeding swaths thus leaving the rough surface between the swaths. Indeed, with the combined rotary tiller and seed drill behind a tractor on stroke wheels it is possible to reduce the seeding swath or strip to as narrow as 5 cm.

Thus leaving more of the field surface in rough clods and therefore less susceptible to erosion than finely crumbled soil.

With careful use of modern technical equipment it is possible to halt erosion and maintain a healthy, good conditioned soil for the production of a good crop.

If we cultivate our soil keeping the above points in mind we will preserve a loose and living soil. A study has shown that if we cultivate the soil in the conventional way, there are 250,000 soil animals per hectare and 1,500,000 if we work with maximum tillage and direct sowing. We can see that a healthy, loose soil is the result of a good cultivation. The right way for the modern, progressive farmer is to regard working and cultivating the soil as a unit. He needs the knowledge about his soil, technical developments and new ideas.

<table>
<thead>
<tr>
<th>Field size (length x width) in meter</th>
<th>Efficiency relative reversible mouldboard plough %</th>
<th>Mouldboard plough Efficiency-less %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000 x 300</td>
<td>100</td>
<td>97</td>
</tr>
<tr>
<td>500 x 200</td>
<td>100</td>
<td>94</td>
</tr>
<tr>
<td>300 x 100</td>
<td>100</td>
<td>91</td>
</tr>
<tr>
<td>200 x 50</td>
<td>100</td>
<td>88</td>
</tr>
</tbody>
</table>

660
NON TILLAGE DRY FARMING IN HEAVY CLAY SOILS UNDER
MEDITERRANEAN CLIMATE

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ABSTRACT

Direct-drilling dry-farming in heavy clay soils of Southern Spain have been successfully initiated. In addition to its convenience as a soil conservation measure, zero-tilled soils store more water than conventionally tilled soils, mainly due to a better soil water recharge. Increased stored soil water leads to higher yields on years of insufficient precipitation, typical of rainfed Mediterranean agriculture.

INTRODUCTION

The advent of the tractor into the rainfed farming systems on heavy clay soils of Southern Spain imposed a dramatic change to its agriculture. Up to the fifties roman systems more or less evolved, maintaining a three year rotation. The first year was dedicated to cereals, the second year to a pulse crop to sustain the animal power required for ploughing, and the third year was fallowed since not enough mule or oxen were available to pull ploughs and harrows in such a consistent soils. The energy and mechanical problems were overcome with the tractor. Farmers began to plow giving way to a certain plowman folly, one of whose consequences was the acceleration of soil losses due to erosion. The oil crisis of the early seventies prompted the introduction of non-tillage techniques, specially in the olive orchards, whose soils are more susceptible to erosion due both to their texture, and their phisiography since they are located on moderate to gentle slopes. More recently, reduced tillage has been tried in other dryfarming crops, with considerable successfullness specially on heavy clay soils. This report draw the attention to the reasons of the higher benefits of reduced tillage and direct drilling in these soils.

THE COMPACTION RISK

One of the reasons agronomists allege to justify tillage is the alleviation of soil compaction. Virgin soils tend to
compact in the Earth gravity field due to their own burden. Cultivation increases the pressure accelerating the compaction process. Tillage operations, like mouldboard plough and harrow passes, open new macropores, and by moving the surface layer, leave the soil spongy with enlarged pores where roots penetrate and the liquid and gas exchanges can take place. In the absence of tillage, after a long period in cultivated soils, reduction of pore space and of large pore volume, induces diminishing infiltration rates, which ultimately results in both higher erosion risk and lower water recharge. The augmented soil losses due to runoff erosion have been observed in several Andalucia olive orchards (e.g., Pastor, 1988). Reduced water recharge and subsequent decreases in summer crop yields have been observed as well.

Nevertheless tillage implies a hidden threat, since the horizon under the plow layer is usually compacted due to the tillage implement. This tillage-induced pan, the plow sole, is clearly shown when runoff erosion removes the plowed layer leaving flat bottom gullies where harrow scars in the form of undulating ridges are prominent.

On the other hand, the swelling property of heavy clay soils, act as an internal spring which offset the compaction effects of the overburden. Voorhees (1983) discusses a similar effect, the frost action in wet soils, which was able to reduce up to a half the penetrometer resistance of some Minnesota soils. Soil swelling may be effective in reducing tillage requirements in dry farming.

RESULTS OF REDUCED TILLAGE TRIALS IN SOUTHERN SPAIN, 1982-87

The experiments of reduced tillage, fully described elsewhere (Giráldez et al., in preparation) consist of three treatments: zero tillage or direct drilling over the previous year stubble, ZT; minimum tillage where all the residues were buried by a harrow pass in the fall, MT; and conventional tillage, with straw burning, summer mouldboard plow, and several disk harrow passes. Weed control was accomplished by chemical spraying in zerotillage and minimum tillage when required. The soil in the main experiment place is a vertisol, typic chromoxerert, of the Carmona series, with high clay content of smectite-type. The climate is typical mediterranean where the annual rainfall, otherwise highly variable around the average value of 450 mm, is concentrated in the fall-winter months with a low about december and occasional rains at the beginnings of spring. The higher temperatures coincide with the low rainfall period resulting in substantial water stress for the summer crops in the absence of irrigation.

Soil water was measured by gravimetric methods on auger extracted samples at periodic intervals. Bulk densities
were determined by SARAN coating and submerging samples weighing. Penetration resistance was measured by a standard ASAE penetrometer whose full set up was developed by Agüera (1986).

Table 1 summarizes the yields of the several crops grown under the different treatments. It is of yields apparent the notable benefit of reduced tillage interm, without accounting for the reduction in soil losses and production costs, in spite of the differences in weather along the experimental period.

Among several reasons, the most favourable water balance stands out. Figure 1 shows the evolution of the water profiles as well as the rainfall events during 1983-84 year. The almost initially equal profiles were recharged after the fall rains, but zerotilled soils had more water deep in the profile than conventionally-tilled soils. Later, the greater a water extraction by the crop chickpeas, sown on the middle of march, left the zerotilled soils drier than conventionally tilled soils. This greater extraction resulted in higher crop yield (Table 1).

The higher cumulative infiltration of non tilled soils indicate the absence of impeding layers. Penetrometer profiles are summarized in figure 2. It can be appreciated the lack of permanent plow soles, in any of the treatments. There is only one increase in penetrometer resistance in the September reading in the minimum tillage treatment due to the effect of the pass for burying the straws, which disappeared at the time of the next reading. The rainy period decreases most resistances both in the 0-30 and 90-60 cm depth intervals.

In the absence of impeding layers, soil water content differences must be attributed to better recharge of nontilled soils. Diffusivity measurements of undisturbed 5 cm OD cylindrical soil samples by the not-air method (Martin, 1988 unpublished) reveal almost similar water transmitting properties of both tilled and nontilled soils with a certain advantage to the tilled ones. Nevertheless, the presence of desiccation cracks is more conspicuous in nontilled soils. Cracks remain open during summer in nontilled soils whereas they are covered by the plow in tilled, conventional and minimum, treatments. Therefore water recharge goes preferentially along wide surface-open cracks (Beven and Germann, 1982). It has been proposed in the past to promote crack opening by leaving implanted rows as a means of increasing water recharge (Johnson, 1962).

CONCLUSIONS

Reduced tillage in heavy clay soils by keeping surface cracks increases the soil water recharge, which allows high
summer crop yields under dryfarming. We have not observed plow pan development in the profile due to shrinking-swelling mechanism which behaves as an internal spring that avoids gravity-induced compaction.

REFERENCES


Table 1. Crop yields in heavy clay soils of Carmona under different tillage treatments.

<table>
<thead>
<tr>
<th>Year</th>
<th>Crop</th>
<th>Rainfall</th>
<th>Treatment</th>
<th>Average yield Kg/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>1982/83</td>
<td>Sunflower</td>
<td>263</td>
<td>direct drilled</td>
<td>750 ± 105</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>minimum tillage</td>
<td>679 ± 120</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>conventional tillage</td>
<td>352 ± 70</td>
</tr>
<tr>
<td>1983/84</td>
<td>Chickpeas</td>
<td>544</td>
<td>direct drilled</td>
<td>611 ± 337</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>minimum tillage</td>
<td>536 ± 412</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>conventional tillage</td>
<td>565 ± 307</td>
</tr>
<tr>
<td>1984/85</td>
<td>Wheat</td>
<td>545</td>
<td>direct drilled</td>
<td>5315 ± 941</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>minimum tillage</td>
<td>5046 ± 998</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>conventional tillage</td>
<td>5536 ± 1003</td>
</tr>
<tr>
<td>1985/86</td>
<td>Sunflower</td>
<td>464</td>
<td>direct drilled</td>
<td>1249 ± 84</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>minimum tillage</td>
<td>1346 ± 163</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>conventional tillage</td>
<td>1558 ± 162</td>
</tr>
<tr>
<td>1986/87</td>
<td>Broadbeans</td>
<td>493</td>
<td>direct drilled</td>
<td>2717 ± 257</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>minimum tillage</td>
<td>2300 ± 258</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>conventional tillage</td>
<td>2333 ± 536</td>
</tr>
</tbody>
</table>
Figure 1. Evolution of a) soil water profiles in the 1983-84 year; b) tendays rainfall at Carmona (Sevilla)

b) Distribución de la lluvia decenal en Tomelil, 1983-84

a) Evolución de los perfiles de humedad
Figure 2. Evolution of average resistance to penetration, MPa, on the a) 0-30 cm, and b) 30-60 cm soil depth intervals.
TIMING AND COORDINATION OF TILLAGE OPERATIONS FOR MAXIMUM COTTON PRODUCTION

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² Assistant Professor, Department of Plant Science, South Dakota State University
³ Professor, Department of Agronomy and Soils, Auburn University

ABSTRACT

Short term droughts frequently limit cotton (Gossypium hirsutum L.) production on Coastal Plain soils in Alabama, USA. Root restricting hard pans also limit the quantity of water available to the growing crop. Tillage and cover crop systems must be coordinated to provide adequate soil moisture at planting time as well as throughout the growing season. Treatments in this 2 year field study included rye (Secale cereale L.) mulch, fall and spring primary tillage combinations, and seedbed preparation comparisons. In both 1985 and 1986 the lowest bulk densities were found in the plots that had been subsoiled and bedded in the fall. In 1985 the highest seed cotton yield resulted from turning and bedding in the spring. In 1986 seed cotton yield was maximized by turning and discing in the spring. In both years, the tillage practice that produced the lowest yield was the in-row-subsoil treatment in the rye mulch.

INTRODUCTION

Cultural practices in the production of cotton have changed with the development of larger, more powerful tractors and new designs in tillage implements. Until 1930 man and animal power were the prime movers in cotton production. Horse and mule drawn tools were used to prepare seed beds and plant the crop. Little attention was paid to soil compaction. Repeated trips over the field with large equipment can lead to the development of root restricting plow pans. Some of the physical properties of ultisols in the Southeastern U.S. make them very sensitive to compaction. Camp and Lund, 1964 made soil density measurements on a naturally occurring Norfolk sandy loam soil (Typic Paleudult). They found a very compact layer at the 19 - 23 cm depth. The bulk densities in this zone ranged from 1.8 to 1.9 g/cc. This condition occurs in many soils in the Southeastern U.S. According to Campbell et al., 1974 the greatest amount of compaction occurs when tillage is done on soils whose water content is at a level best suited for crop growth. They also found that chiseling
a soil to a depth of 38 cm disrupted the compact A₂ horizon, reduced root impedance, increased water infiltration and increased rooting depth.

In the Southeastern U.S. spring rains often delay or prevent beneficial deep tillage operations and adequate seedbed preparation. Tillage methods currently in use vary widely as to depth, degree of soil inversion and fineness of pulverization. In recent years, there has also been interest in the use of cover crops in limited tillage systems. A crop of rye is planted in the fall, as a soil conserving measure, and then is chemically killed in the spring prior to planting. In order to evaluate different tillage systems for cotton production a study was initiated in the fall of 1984.

MATERIALS AND METHODS

Field studies were conducted in 1985 and 1986 at the E.V. Smith Research Center in Macon County, Alabama (Lat. 32° 26' N; Long 85° 54' E.) on a Norfolk sandy loam soil (fine, loamy, siliceous, thermic Typic Paleudult). Initial soil pH was 6.2 and soil test values were 93 kg/ha P, 150 kg/ha K and 1,030 kg/ha Ca. organic matter was .94% and the cation exchange capacity was 6.4 meq/100 g. The test area was fertilized according to soil test recommendations.

The experimental design was a randomized complete block with four replications. Treatments consisted of three primary tillage systems (subsoiling, turn plowing, and chiseling) in combination with two secondary tillage systems (bedding and discing) done either in the fall or spring. Additional treatments included chiseling, turning, or subsoiling in the row in a rye cover crop (Table I). A Brown-Harden ro-till was used for the in-row subsoil treatment. The rye in these plots was killed with paraquat 10 days prior to planting. The ro-till was used 2 weeks before planting. Plots consisted of four 92 cm rows 20 meters long.

TABLE I

<table>
<thead>
<tr>
<th>Treatments</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Subsoil fall, bed fall</td>
<td>9. Turn fall, disc spring</td>
</tr>
<tr>
<td>2. Subsoil fall, bed spring</td>
<td>10. Turn spring, bed spring</td>
</tr>
<tr>
<td>3. Subsoil fall, disc spring</td>
<td>11. Turn spring, disc spring</td>
</tr>
<tr>
<td>4. Subsoil spring, bed spring</td>
<td>12. Chisel fall, bed fall</td>
</tr>
<tr>
<td>5. Subsoil spring, disc spring</td>
<td>13. Chisel fall, bed spring</td>
</tr>
<tr>
<td>6. Subsoil spring, disc spring</td>
<td>14. Chisel fall, disc spring</td>
</tr>
<tr>
<td>7. Turn fall, bed fall</td>
<td>15. Chisel spring, bed spring</td>
</tr>
<tr>
<td>8. Turn fall, bed spring</td>
<td>16. Chisel spring, disc spring</td>
</tr>
<tr>
<td>Treatment in Rye Cover Crop</td>
<td></td>
</tr>
<tr>
<td>17. Chisel spring, disc spring</td>
<td></td>
</tr>
<tr>
<td>18. Turn spring, disc spring</td>
<td></td>
</tr>
<tr>
<td>19. In-row subsoil</td>
<td></td>
</tr>
</tbody>
</table>
The three primary tillage implements used were, a John Deere 900 V-Ripper, a John Deere 4200 four bottom two-way turn plow, and a Ford spring tine chisel plow. A John Deere 4 row bedder and a John Deere 210 disk harrow were used for the secondary tillage treatments.

The subsoiler was pulled to a depth of 41 cm, the chisel plow operated in the top 20 cm of soil. The turn plots were plowed to a depth of 25 - 30 cm.

In the 1985 crop year, the fall tillage was done on 13 November 1984 and the spring tillage on 2 April 1985. In the 1986 crop year, fall tillage was done on 5 October 1985 and the spring tillage on 28 March, 1986. The test was planted on 20 April in 1985 and 22 May in 1986. The cultivar used both years was DPL-90.

Bulk density was measured in the row, in the top 25 cm of soil. Moisture content was measured by weighing the soil cores removed in the bulk density determination process, oven drying, and re-weighing. These measurements were made 30 days after planting. The two center rows of each plot were mechanically harvested and weighed for yield results.

RESULTS AND DISCUSSION

1985

Rainfall distribution was very good in 1985 (Table II), with spring precipitation being slightly above normal.

TABLE II

Rainfall at E.V. Smith Research Center
by year during the growing season

<table>
<thead>
<tr>
<th>Month</th>
<th>1985 (cm)</th>
<th>1986 (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>April</td>
<td>6.32</td>
<td>0.00</td>
</tr>
<tr>
<td>May</td>
<td>7.18</td>
<td>2.74</td>
</tr>
<tr>
<td>June</td>
<td>7.44</td>
<td>1.27</td>
</tr>
<tr>
<td>July</td>
<td>16.20</td>
<td>9.02</td>
</tr>
<tr>
<td>August</td>
<td>8.20</td>
<td>15.24</td>
</tr>
<tr>
<td>September</td>
<td>3.24</td>
<td>8.64</td>
</tr>
<tr>
<td>Total</td>
<td>49.28</td>
<td>36.91</td>
</tr>
</tbody>
</table>

Thirty days after planting the treatment with the lowest bulk density (1.45 g/cc) occurred in the plots that were fall subsoiled, fall bedded (Table III). Bedding in the spring after fall subsoiling increased bulk density as compared to fall bedding. Spring discing after fall
TABLE III

Soil bulk density 30 days after cotton planting-1985, 1986

<table>
<thead>
<tr>
<th>Primary Tillage</th>
<th>Secondary Tillage</th>
<th>Bed</th>
<th>Fall</th>
<th>Bed</th>
<th>Spring</th>
<th>Disc</th>
<th>Spring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall</td>
<td></td>
<td>1.45</td>
<td>1.48</td>
<td>1.55</td>
<td>1.65</td>
<td>1.58</td>
<td>1.58</td>
</tr>
<tr>
<td>Subsoil</td>
<td></td>
<td>1.52</td>
<td>1.51</td>
<td>1.55</td>
<td>1.57</td>
<td>1.58</td>
<td>1.57</td>
</tr>
<tr>
<td>Turn</td>
<td></td>
<td>1.58</td>
<td>1.50</td>
<td>1.58</td>
<td>1.65</td>
<td>1.58</td>
<td>1.65</td>
</tr>
<tr>
<td>Chisel</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spring</td>
<td></td>
<td>1.50</td>
<td>1.88</td>
<td>1.52</td>
<td>1.77</td>
<td>1.55</td>
<td>1.95</td>
</tr>
<tr>
<td>Subsoil</td>
<td></td>
<td>1.48</td>
<td>1.86</td>
<td>1.52</td>
<td>1.62</td>
<td>1.50</td>
<td>1.88</td>
</tr>
<tr>
<td>Turn</td>
<td></td>
<td>1.50</td>
<td>1.81</td>
<td>1.47</td>
<td>1.62</td>
<td>1.50</td>
<td>1.81</td>
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<tr>
<td>Chisel</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1985 FLSD (.10) = .20; 1986 FLSD (.10) = .22

Tillage treatments in rye cover crops

Subsoiling further increased bulk density. The fall turn plots followed this same trend but fall chiseling did not. Timing or type of secondary tillage operation had no effect on the bulk density of fall chiseled plots. In general bulk densities tended to be lower when tillage was done in the spring rather than the fall.

Soil moisture content was highest in the three treatments occurring in the rye cover crop (Table IV). The moisture content for the spring chisel-disc treatment was also high (9.2%). This may be the result of higher than normal rainfall and the inability of the spring tine chisel plow to penetrate the plow plan and allow downward drainage of the water.

TABLE IV

Soil moisture 30 days after planting cotton-1985, 1986

<table>
<thead>
<tr>
<th>Primary Tillage</th>
<th>Secondary Tillage</th>
<th>Bed</th>
<th>Fall</th>
<th>Bed</th>
<th>Spring</th>
<th>Disc</th>
<th>Spring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall</td>
<td></td>
<td>5.2</td>
<td>6.2</td>
<td>5.2</td>
<td>6.2</td>
<td>6.0</td>
<td>7.1</td>
</tr>
<tr>
<td>Subsoil</td>
<td></td>
<td>6.2</td>
<td>7.3</td>
<td>5.8</td>
<td>7.5</td>
<td>6.8</td>
<td>7.8</td>
</tr>
<tr>
<td>Turn</td>
<td></td>
<td>5.8</td>
<td>6.9</td>
<td>6.5</td>
<td>6.4</td>
<td>6.5</td>
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<tr>
<td>Chisel</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spring</td>
<td></td>
<td>6.0</td>
<td>7.5</td>
<td>5.2</td>
<td>6.2</td>
<td>8.2</td>
<td>3.6</td>
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<tr>
<td>Subsoil</td>
<td></td>
<td>6.0</td>
<td>8.7</td>
<td>6.2</td>
<td>7.0</td>
<td>7.5</td>
<td>7.9</td>
</tr>
<tr>
<td>Turn</td>
<td></td>
<td>6.2</td>
<td>7.2</td>
<td>9.2</td>
<td>6.5</td>
<td>12.0</td>
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<tr>
<td>Chisel</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1985 FLSD (.10) = 2.5; 1986 FLSD (.10) = 2.4

Tillage treatments in rye cover
Among the fall tillage treatments, yields were higher when plots were bedded in the spring rather than the fall (Table V). The subsoil treatment proved to be the most effective fall tillage practice.

**TABLE V**

<table>
<thead>
<tr>
<th>Primary Tillage</th>
<th>Bed Fall</th>
<th>Bed Spring</th>
<th>Disc Spring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall Subsoil</td>
<td>1,738</td>
<td>2,195</td>
<td>2,355</td>
</tr>
<tr>
<td>Turn</td>
<td>1,478</td>
<td>1,758</td>
<td>1,882</td>
</tr>
<tr>
<td>Chisel</td>
<td>1,730</td>
<td>1,930</td>
<td>2,012</td>
</tr>
<tr>
<td>Spring Subsoil</td>
<td>2,157</td>
<td>1,021</td>
<td>1,013(^1)</td>
</tr>
<tr>
<td>Turn</td>
<td>2,675</td>
<td>1,295</td>
<td>1,372</td>
</tr>
<tr>
<td>Chisel</td>
<td>2,309</td>
<td>1,043</td>
<td>1,273</td>
</tr>
</tbody>
</table>

F\(_{LSD} (.10) = 202\)

**Tillage treatments in rye cover**

The spring turn, spring-bed treatment was the highest yielding treatment in the test (2,675 kg/ha seed cotton). With all three primary spring tillage treatments, yields were greatly reduced when discing followed as opposed to bedding the in-row subsoil treatment in the rye mulch resulted in the lowest yield.

1986

Rainfall distribution was poor in 1986 (Table II). Spring precipitation was the lowest ever recorded.

Thirty days after planting, the lowest bulk density was recorded in the fall subsoil, fall bed treatment (Table III). The plots with the highest bulk density were those that were subsoiled in the row before planting.

Soil moisture content was consistently higher in plots that were turn plowed (Table IV); this occurred both in the fall and spring tillage systems. The lowest soil moisture content, 3.6%, occurred in the in-row subsoiled plots in the rye mulch.

In the fall tillage system, yields were improved when plots were bedded in the fall as compared to those that were bedded or disced in the spring (Table VI). There were no significant differences among the three primary tillage systems when they were fall bedded. The highest yield in the test, 2,697 lbs, resulted from spring turning and discing. Yields were improved by discing after spring primary tillage rather than bedding. This was probably due to the extremely dry conditions early in the growing season.
Good yields also were obtained by turning in the rye cover crop. In 1986 the lowest yielding treatment proved to be the in-row subsoil treatment.

### TABLE VI

Seed cotton yields as affected by tillage, 1986

<table>
<thead>
<tr>
<th>Primary Tillage</th>
<th>Secondary Tillage</th>
<th>---</th>
<th>---</th>
<th>---</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fall Bed Fall</td>
<td>Disc Spring</td>
<td>Disc Spring</td>
<td></td>
</tr>
<tr>
<td>Fall Subsoil</td>
<td>2,088</td>
<td>1,746</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Turn</td>
<td>2,088</td>
<td>2,050</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chisel</td>
<td>1,912</td>
<td>1,811</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spring Subsoil</td>
<td>1,774</td>
<td>1,505</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Turn</td>
<td>1,948</td>
<td>2,818</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chisel</td>
<td>2,013</td>
<td>2,217</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**FLSD (.10) = 224**

1 Tillage treatments in rye cover crop

### CONCLUSIONS

In 1985, a year of adequate moisture, highest yields resulted from turning and bedding in the spring. In 1986, an exceptionally dry year, highest yields were obtained by turning and discing. Bedding involves a greater degree of soil mixing than does discing, consequently more moisture is lost. The very low spring rainfall amounts in 1986 were not adequate to wet the beds by planting time and ultimately resulted in yield reductions. The use of moldboard plow for primary spring tillage operations does appear to result in consistently good seed cotton yields.

The lowest yields in both 1985 and 1986 resulted from the use of an in-row subsoiler before planting in a rye mulch. In a wet year the rye may prevent the soil from adequately drying, and result in a poor seedbed. In a year with little spring precipitation the rye may use a great deal of the available water in the soil profile and leave very little for the growth and development of the cotton crop. Turning under of the cover crop, however, did produce acceptable yields in both years of the test.

### PUBLICATIONS


CULTIVATION SYSTEMS FOR CLAY SOILS

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Institute of Arable Crops Research, Rothamsted Experimental Station, Harpenden, Herts AL5 2JQ, UK.

ABSTRACT

Clay soils comprise about 40% of soils on which cereals are grown in England and Wales. Simplified tillage systems have given yields equal to or greater than those after ploughing when clay soils were drained and crop residues burnt. Improved continuity of macropores in direct-drilled soil offset the reduction in total porosity. But if the land was not drained, air-filled porosity was reduced to a greater extent with simplified tillage than with ploughing. Where straw residues were left after harvest, crop growth was little affected if residues were ploughed-in to a depth of 150 mm but systems that left residues on the surface or incorporated them only shallowly gave reduced yields.

INTRODUCTION

Since the early 1970's more autumn-sown cereals have been grown and about 40% of the land on which they are planted have a clayey texture (Cannell et al. 1978). Three types of husbandry practice currently influence the management of clay soils, tillage, straw disposal and drainage.

Traditionally, mouldboard ploughing was used to prepare land and aid weed control. However, in wet autumns the plough share can cause smearing and poor traction slows the formation of the seedbed. In dry autumns, harsh clods which are not easily broken down often remain in the seedbed. In contrast, tillage systems using tined implements working shallowly (100 mm or less) or even direct drilling into untilled soil are now possible with the herbicides available for weedkilling. Such systems reduce the time required to establish a crop but soil structure obviously differs under these cultural practices. Nevertheless Stegel et al. (1984) found that for clay soils the characteristics of the topsoil, good structural stability, greater resistance to compaction and a tendency to recover from damage, made them most suitable for direct drilling.

The best cultivation practices can give heavy yields on these clay soils, and straw production can exceed 10 t ha⁻¹ in good years. In England, specialisation of enterprises has led to intensive cereal production in the east with animal production concentrated in the west, and therefore, on intensive cereal farms there is much surplus straw that must be disposed of in some way. Many farmers opted to burn straw, but the introduction of more stringent conditions for the control of burning has led them to consider the alternative of incorporating straw into the soil on which it was grown. The choice has often been influenced by environmental considerations rather than by a rational strategy for soil cultivation.
Clay soils commonly have poor permeability and evidence from lysimeter studies suggested that the watertable needs to be maintained at least 500 mm below the soil surface to maintain yields of winter wheat. In a climate where rainfall exceeds potential evaporation by 200 mm, drainage is an important management option. However, for cereal production, the necessary spacing of drains to lower the watertable can only be practicable using cheap close-spaced collectors linked to widely spaced pipe drains. For England and Wales the ideal system is of pipe drains on about 50 m spacing laid at 900 mm depth with some 500 mm gravel fill above. Mole drains are drawn between these drains at 600 mm depth and 2 m apart. The benefit of such a system under all types of tillage has rarely been tested.

The aim of this study was to evaluate tillage, drainage and straw disposal practices for the most effective cultivation of clay soils for autumn-sown crops.

METHODS

Effects of tillage were evaluated on a calcareous clay soil, Evesham series, and on three non-calcareous stagnogley soils, two on Denchworth soil series and one on Lawford series. At all sites mouldboard ploughing was compared with direct drilling. Tine cultivation was included in the comparison on the Evesham and Lawford soils. Methods of straw disposal were also studied on the latter. Burning straw was compared with incorporating chopped straw to different depths or leaving it on the soil surface. Drainage effects were investigated on the Denchworth series and plots were either undrained or drained according to the recommended practice.

RESULTS

Soil Physical Conditions for Root Growth. All the soils exhibited considerable swell/shrink behaviour. Thus differences in the density of the topsoil between ploughed and simplified cultivation treatments were often small by spring, and on the Lawford soil two years elapsed before the porosity of direct-drilled plots became significantly less than in ploughed plots (Table I). Simplified tillage systems reduced the volume of pores greater than 50 μm so increasing the proportion of water filled pores (Table II). The continuity of porosity was reduced at the interface

<table>
<thead>
<tr>
<th>Year of experiment</th>
<th>Plough (75 mm)</th>
<th>Tine (75 mm)</th>
<th>Direct-drill (75 mm)</th>
<th>Sed (75 mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.87</td>
<td>0.86</td>
<td>0.87</td>
<td>0.029</td>
</tr>
<tr>
<td>2</td>
<td>1.06</td>
<td>1.07</td>
<td>1.07</td>
<td>0.024</td>
</tr>
<tr>
<td>3</td>
<td>0.92</td>
<td>0.92</td>
<td>1.03</td>
<td>0.019</td>
</tr>
</tbody>
</table>
between the cultivated layer and subsoil in the ploughed land because of the action of the plough and the passage of the tractor wheels in the furrow. Thus in direct-drilled soil (Denchworth series) the hydraulic conductivity at saturation was \(1.94 \pm 0.137 \text{ m day}^{-1}\) but only \(1.07 \pm 0.183 \text{ m day}^{-1}\) in ploughed land. In shallow-tined plots on the Lawford soil air permeability was reduced at about 100 mm and 300 mm depth due to compression by the tines and by wheelings. Hydraulic conductivity was greater in the subsoil of direct-drilled land down to a depth of 500 mm although tillage was confined to a maximum of 250 mm on the ploughed land.

**TABLE II.** Effect of tillage on total porosity and volume of pores drained at -6 kPa (>50 \(\mu\)m equivalent diameter). Samples taken from 80-120 mm depth in Lawford series soil.

<table>
<thead>
<tr>
<th>Tillage</th>
<th>Porosity Total</th>
<th>Pores &gt;50 (\mu)m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plough</td>
<td>0.55</td>
<td>0.09</td>
</tr>
<tr>
<td>Tine cultivation</td>
<td>0.52</td>
<td>0.06</td>
</tr>
<tr>
<td>Direct-drill</td>
<td>0.51</td>
<td>0.05</td>
</tr>
<tr>
<td>sed</td>
<td>0.011</td>
<td>0.009</td>
</tr>
</tbody>
</table>

In the field topsoil density was unaffected by the presence or absence of straw. In the laboratory even incorporation of 20 t ha\(^{-1}\) straw (2% straw by weight) did not reduce bulk density of the Lawford soil although it did modify the moisture release characteristics of the topsoil, suggesting that its introduction had increased the proportion of small pores. This resulted in a greater hydraulic conductivity where straw was retained but water was also held close to the soil surface as the soil wetted up in autumn.

Drainage had little effect on the air-filled porosity of ploughed land but greatly increased values in the topsoil of direct-drilled plots (Fig. 1). Hydraulic conductivity was greater in the topsoil of drained land. However, there was only a small reduction in water availability as a result of drainage.

Root Growth. Roots penetrated more rapidly into the subsoil of direct-drilled land but those in ploughed land tended to catch up later in the season unless differences in water supply persisted between treatments. Readily soluble phosphorus accumulated in the top 50 mm of direct-drilled soil and encouraged the proliferation of roots near the soil surface but there was no evidence that uptake was affected.

Root distribution was not directly affected by the small changes in those physical properties caused by the presence of straw, but where it was left on the surface, there was poorer shoot growth which eventually slowed the rate of root penetration.

Drainage greatly modified root distribution. The rate of penetration of main axes was little affected by drainage but lowering the watertable from 180 mm to 450 mm below the soil surface enhanced root density in this zone and increased water extraction compared with undrained soil. The uptake of nitrogen was significantly reduced in the undrained land
Fig. 1. Histogram of air-filled porosity in drained and undrained land that was either ploughed or direct-drilled.

Fig. 2. Histogram of yields from Evesham, Denchworth and Lawford soils on which simplified cultivation was compared with traditional ploughing. * Significant differences between yields. Cross-hatching indicates oilseed rape.
and this could have been the result of poorer root development in the upper subsoil.

TABLE III. Effect of straw on yields of winter wheat.

<table>
<thead>
<tr>
<th>Straw</th>
<th>Depth of tillage (mm)</th>
<th>0*</th>
<th>50</th>
<th>150</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Burnt Retained</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1985</td>
<td>6.3 3.0</td>
<td>5.8</td>
<td>5.5</td>
<td>5.6</td>
</tr>
<tr>
<td>1986</td>
<td>7.8 6.0</td>
<td>7.6</td>
<td>6.5</td>
<td>7.2</td>
</tr>
<tr>
<td>1987</td>
<td>7.2 6.2</td>
<td>5.8</td>
<td>5.7</td>
<td>5.2</td>
</tr>
</tbody>
</table>

* direct-drilled

Crop Growth and Yield. In dry autumns cloddy seedbeds delayed growth on ploughed land but establishment was a problem for direct-drilled crops only in the first year. Soil disturbance to just 75 mm was sufficient for good establishment. The subsequent growth of the crops assessed by measurement of light interception was faster after simplified tillage, but differences in the time to canopy closure were only small. As a result, yields were on average similar irrespective of cultivation treatment, though there were treatment effects in particular seasons (Fig. 2).

Direct drilling into straw led to patchy crops; blocked coulters caused uneven seed distribution, slug numbers increased in the presence of straw, and there was often increased incidence of disease. Straw depressed yield in the Lawford clay soil except when it was ploughed to 150 mm and effects on yield have often been similar after direct drilling and shallow incorporation (Table III).

Drainage increased the rate of dry matter production and the yield benefit has averaged 9 percent. There was an interaction between drainage and cultivation with bigger increases after direct drilling than after ploughing (Table IV).

TABLE IV. Effects of drainage and tillage on the yield of winter crops.

<table>
<thead>
<tr>
<th>Drainage</th>
<th>Total grain yield (t ha⁻¹) for 9 crops.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drained</td>
<td>Undrained</td>
</tr>
<tr>
<td>64.7</td>
<td>59.17</td>
</tr>
</tbody>
</table>

Drainage - cultivation interactions for winter wheat: annual average yield (t ha⁻¹) for 4 crops.

<table>
<thead>
<tr>
<th></th>
<th>Drained</th>
<th>Undrained</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ploughed</td>
<td>8.45</td>
<td>8.30</td>
</tr>
<tr>
<td>Direct-drilled</td>
<td>9.08</td>
<td>8.21</td>
</tr>
<tr>
<td>sed</td>
<td>0.053</td>
<td></td>
</tr>
</tbody>
</table>
DISCUSSION

The increase in soil porosity due to ploughing was apparently offset by a reduction in the continuity of macropores so that roots grew more rapidly to depth in land under simplified tillage. However, differences in root growth did not limit nutrient uptake or result in consistently greater yields of autumn-sown crops when residues were burnt. The improvement in root growth due to drainage was consistent and mainly affected branching. Uptake of nitrogen was greater from drained land and yield benefits from subsoil drainage averaged 9%. Drainage increased air-filled porosity in the topsoil but effects were least in ploughed soil. This may be an important reason why yields showed that better drainage was needed for direct-drilled crops of winter wheat than for ploughed crops.

The constraints to adopting simplified tillage on clay soils appear to be mostly associated with the presence of crop residues at or near the soil surface. As separation of straw and seed appears to be important the use of improved skim ploughs may provide a suitable alternative to tines for seedbed preparation but we have not studied this. Direct drilling is not practicable when the weight of residues currently produced is left on the surface. These results are consistent with the findings of Stengel et al. (1984) that clay soils have properties that make them suitable for simplified tillage but that other factors such as climate might impose limitations (Cannell et al., 1978).

CONCLUSIONS

1. On clay soils simplified tillage systems offer an alternative to ploughing that is not detrimental to yield.
2. These techniques are less suitable when straw cannot be burned.
3. Drainage to clay soils has had the most consistent effect on improving soil conditions for crop growth and yield.
4. Better drainage is necessary for simplified tillage systems such as direct drilling.

REFERENCES


CULTIVATION SYSTEMS AND THE LEACHING OF NITRATES

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2 Institute of Grassland and Animal Production, Welsh Plant Breeding Station, Aberystwyth, Dyfed SY23 3EB, U.K.
3 Field Drainage Experimental Unit, ADAS, Cambridge CB2 2LF, U.K.

ABSTRACT

With the exception of one dry winter, an average of 30 kg N ha\(^{-1}\) nitrate was intercepted by mole and pipe drains in the subsoil of a clay soil after an autumn-sown crop was established by direct-drilling. Soil cultivated to 250 mm with tines or by ploughing lost an additional 10 kg N ha\(^{-1}\) and increased the concentration of nitrates in the water moving to the watertable. Spring losses depended on rainfall in the 10 days following fertilizer application but were generally small in comparison with the winter losses which mainly came from mineralization of organic matter. Additional losses were identified in water flowing in surface runoff and at the interface between topsoil and subsoil but these components were small except when there were no drains in the subsoil. Denitrification caused losses up to 10% of the total lost by leaching.

INTRODUCTION

Soil contents of mineral nitrogen are greatly enhanced after fertilizer application in spring but at harvest there is generally little remaining in the soil. However, by early November there can be more than 100 kg N ha\(^{-1}\) in the top metre following mineralization of organic nitrogen, and this total can vary according to the system of tillage employed. In England, much of the nitrate-nitrogen is susceptible to leaching, especially during the winter when an average of 200 mm through drainage can be expected in the cereal growing areas. Some of the mineralized nitrogen can also be lost by denitrification from soils that become anaerobic because of natural or induced slow permeability. The rate and pathways for downwards movement of water and oxygen are greatly dependant on soil structure and hence can also be affected by tillage. Thus the total losses of nitrogen and the concentration of nitrates moving in drainage to aquifers and water courses could well be modified by the cultivation system used. In this paper we describe the effects of tillage practice on the losses of nitrogen from a clay soil and on the concentration of nitrates in drainage water.

METHODS

The experiment was started in 1978 on a Denchworth series clay soil (a verti-eutric gleysol) near Oxford. In summary, twenty plots were isolated with polythene barriers to stop water moving across the slope, and also by gravel-filled trenches with a pipe drain that prevented water moving downslope. Within each plot collectors were installed to intercept water
moving over the soil surface (surface runoff) and water that flowed in
the topsoil immediately above the interface with the subsoil (interflow).
In half the plots pipe drains were inserted at 900 mm on a 46 m spacing;
mole drains at 600 mm depth on a 2 m spacing were drawn into the gravel
overlying the pipe drain. This mole and pipe drain system collected
water that was moving to the watertable.

Water from each source passed in closed pipes to weir chambers where
flow-rates were recorded autographically. At intervals samples were
automatically collected for analysis from a U-bend trap at the end of the
closed pipes. Nitrate concentrations were determined colorimetrically
after reduction to nitrite, or by ion-specific electrode. Ammonium-N and
nitrite-N were small compared with nitrate-N and were ignored in
computing results.

Denitrification was determined in the field using the acetylene-
blocking technique.

In the first two seasons crops were established following tine culti-
vation to about 250 mm. Subsequently half the plots containing mole
drains and half those without were ploughed to 200 mm before a seedbed
was formed by secondary operations. The remaining plots were direct-
drilled. The straw residues were burnt after harvest. From 1984 ash was
incorporated within 36 h, to meet legal requirements. The direct-drilled
plots had the least possible soil disturbance necessary to comply with
the regulations but the same implement, discs or tines, was used on all
plots. There was usually about 4 weeks between this soil disturbance
causd during incorporation of ash and the preparation of the seedbed for
the next cereal crop. The test crop was winter wheat but three break-
crops were grown: winter oats in 1982-3 and 1986-7, and winter oil-seed
rape in 1984-5.

RESULTS

Surface runoff water removed an average of less than 1 kg N ha⁻¹ from
soil under tine cultivation and even in undrained land up to 50% of total
runoff was over the soil surface, nitrate losses were small. When the
tillage treatment was changed for the 1981 crop, losses generally
remained small, but in direct-drilled land total nitrate lost in surface
runoff increased (Table I). An exception was noted under the wheat crop
harvested in 1983 where there were substantial losses in surface runoff
from direct-drilled plots due to rainfall in the 3 weeks after fertilizer
application, whether in autumn or spring.

Interflow accounted for much of the losses from land without mole
drains. For example in 1980 after tine cultivation, 90% of nitrate-N was
found in interflow water (Table I).

In plots with the mole and pipe system about 90% of nitrate losses were
in water intercepted by this collector after tine cultivation (Table II). After
the change of tillage for the cultivation of the 1981 winter wheat
crop, the mole and pipe drain system still collected the largest
proportion of the nitrate leached but in the direct-drilled plots more
nitrate tended to be lost in runoff (Table II). In part this was due to
the increase in surface flow as a proportion of the total runoff.
TABLE I. Effect of tillage on the loss of nitrate-nitrogen in surface runoff from soil without subsoil drains.

<table>
<thead>
<tr>
<th>Harvest year</th>
<th>Tillage</th>
<th>Nitrate lost (kg N ha(^{-1}))</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Surface runoff</td>
<td>Interflow</td>
<td></td>
</tr>
<tr>
<td>1979</td>
<td>Tine</td>
<td>1.04 (48)*</td>
<td>2.84 (52)</td>
<td></td>
</tr>
<tr>
<td>1980</td>
<td>Tine</td>
<td>0.31 (43)</td>
<td>11.50 (57)</td>
<td></td>
</tr>
<tr>
<td>1981</td>
<td>Plough</td>
<td>0.07 (68)</td>
<td>2.55 (32)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Direct-drill</td>
<td>5.83 (56)</td>
<td>2.85 (44)</td>
<td></td>
</tr>
<tr>
<td>1982</td>
<td>Plough</td>
<td>5.87 (73)</td>
<td>2.69 (27)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Direct-drill</td>
<td>5.90 (83)</td>
<td>2.16 (17)</td>
<td></td>
</tr>
<tr>
<td>1987</td>
<td>Plough</td>
<td>1.32 (77)</td>
<td>4.00 (23)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Direct-drill</td>
<td>4.63 (79)</td>
<td>0.94 (21)</td>
<td></td>
</tr>
</tbody>
</table>

Figures in parentheses indicate the water collected at the two positions expressed as a percentage of the total.

The losses of nitrogen through the mole and pipe drains were divided into those occurring between the drilling of the crop in early autumn and the first application of nitrogen fertilizer in the next spring (winter losses); and those losses following the first topdressing (spring losses). Winter losses (Table III) showed significant seasonal variability, being least under the 1984 crop when there was little drainflow. No fertilizer nitrogen was added to the seedbed of the 1981 and 1987 crops which may account for there being less nitrate lost by leaching in those years. Although no fertilizer nitrogen was added to the seedbed of the 1987 crop, the residues from the previous crop of oilseed rape contributed about 35 kg N ha\(^{-1}\). In other seasons an average of 26 kg N ha\(^{-1}\) was applied in the autumn and the loss in water moving to the watertable was similar for tilled soil, whether tine-cultivated or ploughed, and averaged 46.7 kg N ha\(^{-1}\). Differences between ploughing and direct-drilling were small in the first year after changing the tillage treatments (1981 crop) but about 16 kg N ha\(^{-1}\) less nitrate was lost from direct-drilled soil in the second year, then 25% less subsequently.

With the exception of 1983, spring losses were always considerably smaller than those occurring in winter and were much more variable (Table IV).

TABLE II. Effect of tillage on nitrate losses (kg N ha\(^{-1}\)) from land containing mole and pipe drains in the subsoil.

<table>
<thead>
<tr>
<th>Harvest year</th>
<th>Tillage</th>
<th>Nitrate losses (kg N ha(^{-1}))</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Surface runoff</td>
<td>Interflow</td>
<td>Drains</td>
</tr>
<tr>
<td>1980</td>
<td>Tine</td>
<td>0.2</td>
<td>4.2</td>
<td>55.3</td>
</tr>
<tr>
<td>1981</td>
<td>Plough</td>
<td>2.5</td>
<td>0.8</td>
<td>17.5</td>
</tr>
<tr>
<td></td>
<td>Direct-drill</td>
<td>9.8</td>
<td>2.7</td>
<td>15.5</td>
</tr>
<tr>
<td>1982</td>
<td>Plough</td>
<td>*</td>
<td>2.7</td>
<td>42.5</td>
</tr>
<tr>
<td></td>
<td>Direct-drill</td>
<td>1.2</td>
<td>2.9</td>
<td>26.4</td>
</tr>
</tbody>
</table>

* not measured
### TABLE III. Effect of cultivation on the overwinter leaching of nitrate nitrogen: losses intercepted by the mole and pipe drain system in the subsoil.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Crop</td>
<td>wheat</td>
<td>wheat</td>
<td>wheat</td>
<td>wheat</td>
<td>oats</td>
<td>wheat</td>
<td>oilseed</td>
<td>wheat</td>
<td>oats</td>
</tr>
<tr>
<td>WINTER LOSSES (kg N ha⁻¹)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tine cult</td>
<td>40.1</td>
<td>54.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plough</td>
<td>11.7</td>
<td>41.5</td>
<td>51.2</td>
<td>5.6</td>
<td>41.0</td>
<td>50.4</td>
<td>32.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Direct drill</td>
<td>10.5</td>
<td>25.7</td>
<td>33.2</td>
<td>2.7</td>
<td>27.0</td>
<td>46.1</td>
<td>27.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WINTER DRAIN FLOW (mm)</td>
<td>163</td>
<td>219</td>
<td>198</td>
<td>198</td>
<td>183</td>
<td>73</td>
<td>144</td>
<td>227</td>
<td>190</td>
</tr>
<tr>
<td>Winter Rainfall (mm)</td>
<td>208</td>
<td>365</td>
<td>407</td>
<td>449</td>
<td>409</td>
<td>325</td>
<td>399</td>
<td>447</td>
<td>401</td>
</tr>
<tr>
<td>Soil water deficit before cultivation (mm)</td>
<td>0*</td>
<td>112</td>
<td>114</td>
<td>129</td>
<td>152</td>
<td>137**</td>
<td>170**</td>
<td>92</td>
<td>180</td>
</tr>
<tr>
<td>FERTILIZER-N -autumn application (kg N ha⁻¹)</td>
<td>17</td>
<td>24</td>
<td>0</td>
<td>24</td>
<td>30</td>
<td>17</td>
<td>46</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

* assumes a fully drained profile

** calculated from deficit under grass at the same site adjusted for a tall crop, using factors for a similar crop obtained at a nearby site.
TABLE IV. Effect of cultivation on the leaching of nitrate nitrogen: losses intercepted by the mole and pipe drain system in the subsoil after the first topdressing with nitrogen fertilizer in spring.

<table>
<thead>
<tr>
<th>Harvest year</th>
<th>1979</th>
<th>80</th>
<th>81</th>
<th>82</th>
<th>83</th>
<th>84</th>
<th>85</th>
<th>86</th>
<th>87</th>
</tr>
</thead>
<tbody>
<tr>
<td>FERTILIZER-N -spring application (kg N ha⁻¹)</td>
<td>117</td>
<td>139</td>
<td>149</td>
<td>149</td>
<td>110</td>
<td>223</td>
<td>239</td>
<td>130</td>
<td>100</td>
</tr>
<tr>
<td>SPRING LOSSES (kg N ha⁻¹)</td>
<td>0.0</td>
<td>1.0</td>
<td>5.3</td>
<td>1.0</td>
<td>21.9</td>
<td>0.0</td>
<td>7.7</td>
<td>0.5</td>
<td>0.4</td>
</tr>
<tr>
<td>Plough</td>
<td>6.0</td>
<td>0.7</td>
<td>28.0</td>
<td>0.0</td>
<td>12.8</td>
<td>0.5</td>
<td>0.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Direct drill</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total leaching loss (winter and spring) of nitrogen in water moving to all collectors was extremely varied and ranged from 6.1 kg N ha⁻¹ in the driest year (1984 crop) to 75.3 kg N ha⁻¹ in the wettest (1983 crop).

Tillage increased the concentration of nitrate in the water intercepted by the mole and pipe drains (Table V).

TABLE V. Effect of tillage on nitrate concentrations in water moving to the water table under 1987 crop.

<table>
<thead>
<tr>
<th>Month</th>
<th>Nitrate concentration (µg N ml⁻¹)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Plough</td>
<td>Direct-drilling</td>
</tr>
<tr>
<td>October</td>
<td>34.1 ± 5.83</td>
<td>25.9 ± 2.40</td>
</tr>
<tr>
<td>November</td>
<td>33.0 ± 1.87</td>
<td>23.8 ± 1.98</td>
</tr>
<tr>
<td>December</td>
<td>26.9 ± 1.63</td>
<td>24.7 ± 4.48</td>
</tr>
<tr>
<td>January</td>
<td>20.9 ± 1.07</td>
<td>16.0 ± 0.94</td>
</tr>
<tr>
<td>February</td>
<td>19.6 ± 1.20</td>
<td>16.1 ± 0.90</td>
</tr>
<tr>
<td>March</td>
<td>20.5 ± 1.37</td>
<td>17.4 ± 0.96</td>
</tr>
<tr>
<td>April</td>
<td>15.6 ± 1.65</td>
<td>11.8 ± 0.59</td>
</tr>
<tr>
<td>April*</td>
<td>11.7 ± 1.99</td>
<td>7.0 ± 0.61</td>
</tr>
</tbody>
</table>

* after fertilizer application

Denitrification rates were dependant on tillage and on the presence of subsoil drains. Thus during wet soil conditions under the 1983 crop, peak rates increased from 25 µg N m⁻² h⁻¹ in ploughed soil with subsoil drains to 60 µg N m⁻² h⁻¹ where there were no drains and 300 µg N m⁻² h⁻¹ in direct-drilled soil. This resulted in losses of 3 and 9 kg N ha⁻¹ after ploughing and direct-drilling respectively. Most of this loss occurred in autumn rather than in spring. This increased the combined loss for the year by both leaching and denitrification to 78.3 kg N ha⁻¹ in ploughed soil but only 73.5 kg N ha⁻¹ after direct-drilling.
DISCUSSION

Considerable losses of nitrate nitrogen, up to 78 kg N ha\(^{-1}\), took place in arable land under autumn-sown crops. Most of the losses were in water moving to the watertable but there was a small loss in water flowing downslope in the surface layers. Denitrification losses were about 10\% of the leaching losses. Even in years when no nitrogen fertilizer was applied in autumn, between 17 and 47 kg N ha\(^{-1}\) were lost from the soil in drainage. Except in one dry autumn, winter losses from direct-drilled land averaged 30 kg N ha\(^{-1}\), and tillage increased this figure by 10 kg N ha\(^{-1}\). As in most seasons an average of 26 kg N ha\(^{-1}\) was applied to the seedbed in autumn, effectively all this application was lost through the drains, probably because the crop was small and falling temperatures reduced the demand for nitrate by the shoots. These results strongly indicate that the practice of applying nitrogen fertilizer in autumn should be discouraged.

The difference between losses in drainage between tilled and direct-drilled land could be attributed to several factors. Denitrification was greater in direct-drilled soil than ploughed soil but the differences were less than differences in leaching losses. Direct-drilling increased surface runoff which transported less nitrogen but this was insufficient to account for the whole difference.

The current interest is in processes of mineralization and the pathways of loss for the nitrates released in autumn. Faster flows take place in large pores that are rapidly purged of nitrate and further leaching will depend on diffusion of nitrate from finer pores. Although there are fewer large pores in direct-drilled soil, continuity of vertically oriented macropores is greater than in ploughed soil and water movement to depth is more rapid so that fertilizer nitrogen could be quickly leached. In ploughed soil there are more large pores but the discontinuity associated with the plough sole slows flow and could allow more nitrate to diffuse from the surrounding soil. This would result in a greater concentration of nitrogen in the leachate from ploughed plots and leave less nitrogen available for denitrification. The evidence reported here supports this hypothesis.

CONCLUSIONS

The application of fertilizer nitrogen in autumn is wasteful and seriously increases leaching losses of nitrates to the environment.

Direct-drilling provides an opportunity to reduce leaching losses and the concentration of nitrates in water moving to potable water supplies.
THE EFFECT OF DIFFERENT TILLAGE SYSTEMS ON SOIL WATER MOVEMENT IN AN ARTIFICIALLY DRAINED CLAY SOIL

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¹ADAS Field Drainage Experimental Unit, Cambridge CB2 2LP, UK
²Institute of Arable Crops Research, Rothamsted Experimental Station, Harpenden, Herts AL5 2JQ, UK

ABSTRACT

The effect of direct drilling on the routing of excess winter rainfalls and the efficiency of the drainage system was investigated in a heavy clay soil where mole and pipe drainage is traditionally used. Although direct drilling caused higher surface runoff than deep ploughing, more rapid vertical movement of water also occurred in the subsoil. Interaction with the underdrainage system resulted in a peakier drainflow hydrograph. The implication of higher peak drainflows on current underdrainage design standards is examined. Weather patterns were important in determining the efficiency of the mole drainage system.

INTRODUCTION

In the United Kingdom winter sown crops are frequently grown on impermeable clay soils where field drainage is essential to avoid problems due to waterlogging. Mole drainage is suited to these soils with high clay content which make formation of stable mole channels likely. As a prerequisite to creating a suitable seedbed these soils have been subjected to mouldboard ploughing or tine cultivations. In the mid 1970s there was an increase in the use of direct drilling or simplified cultivation systems as these techniques were quicker, less prone to producing cloddy seedbeds and could be carried out in wet autumns. Although recently the proportion of this land has decreased, environmental considerations may maintain interest in this form of cultivation.

Most of the early trials which established the drainage requirement of arable crops were carried out in conjunction with deep cultivations. Subsequent trials with minimal tillage showed changes occurred in soil structure together in some cases with a change in the runoff pattern. This raised the question that the drainage design requirement for minimum tillage may be different.

In 1978 a ten year experiment was established to examine the interaction between tillage and drainage on crop growth, nitrate leaching and site hydrology. All plot treatments were tined to 250 mm depth for the first two years. Then in 1980 half the plots of each drainage treatment were cultivated by mouldboard ploughing followed by secondary operations to create a seedbed and the others were direct drilled.

This paper reviews the effect of tillage on the removal of winter rainfall from undrained and drained land through the near surface layer and where applicable through the mole-pipe system. The effect of any change in runoff in relation to the drainage requirement is discussed.
**EXPERIMENTAL METHOD**

The site details and drainage systems were fully reported by Cannell et al (1984) and are given in summary here. The 0.5 ha site was located at Brimstone Farm, Oxfordshire on a slowly permeable clay soil belonging to the Denchworth series, typical of the marginal cereal growing areas in the UK. The average slope was 2% across the twenty individually isolated plots. Half the plots were undrained whilst the remainder had pipe drains at 900 mm depth, 46m apart with permeable backfill. Mole drains at 600 mm depth and 2m spacing were drawn down the slope at right angles to the pipes. To enable the effect of the different tillage systems on runoff to be fully evaluated the pipe system installed had been substantially overdesigned on all but two plots.

Drainflow was measured on six plots from both plot drains using autographic V-notch weirs and in later years from individual mole drainage channels using logged tipping bucket recorders. In addition continuous flow measurements were made of surface runoff and interflow (plough layer flow or at the equivalent depth) from these plots as well as a further six undrained plots. Measurements have been made of rainfall, watertable control, soil structure supplemented by counts of earthworm populations and assessment of changes in the effectiveness of the mole drainage channel system.

Autumn sown crops have been established in all years in conjunction with a permanent tramline system. Crop residues have been burnt after harvest. After 1984 the resultant ash was incorporated on all plots with the least possible soil disturbance to conform with the legal requirements (Goss, Howse, Colbourne and Harris, this proceedings).

**RESULTS**

Rainfall and watertable control

The rainfall in each year is given in Table I. Although in most winters the rainfall totals were within 10% of the average, the study period was markedly influenced by two very dry summers with less than 50% of the average rainfall.

Although variations were noted in the watertable control experienced with the different cultivaions the dominant influence was the drainage treatment. The depth to the watertable for the winter months 1980-86 was 15 to 20 cm greater on the drained plots depending on the amount of winter rainfall and the quality of the mole channel system.

Runoff

Quantities of surface runoff from all plots were very dependent on the rainfall pattern and on the drained plots on the effectiveness of the mole channel system. No discernible difference in surface runoff was observed on plots under tine cultivation compared with ploughing but in contrast the change to direct drilling led to very peaky hydrographs and a noticeable increase in surface runoff on both drained and undrained plots (Table II).

Interflow was generally low in all years especially in conjunction with drainage. In contrast flow through the mole channels and pipe
Table I. Rainfall totals 1978-87 expressed as a percentage of the long term average

<table>
<thead>
<tr>
<th></th>
<th>1978/79</th>
<th>79/80</th>
<th>80/81</th>
<th>81/82</th>
<th>82/83</th>
<th>83/84</th>
<th>84/85</th>
<th>85/86</th>
<th>86/87</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oct--Sep</td>
<td>80</td>
<td>95</td>
<td>100</td>
<td>92</td>
<td>99</td>
<td>77</td>
<td>108</td>
<td>91</td>
<td>90</td>
</tr>
<tr>
<td>Nov--Mar</td>
<td>82</td>
<td>106</td>
<td>95</td>
<td>98</td>
<td>93</td>
<td>86</td>
<td>108</td>
<td>98</td>
<td>90</td>
</tr>
<tr>
<td>Jun--Aug</td>
<td>67</td>
<td>115</td>
<td>76</td>
<td>91</td>
<td>44</td>
<td>39</td>
<td>140</td>
<td>68</td>
<td>99</td>
</tr>
</tbody>
</table>

Table II. Mean runoff as a percentage of total runoff per cultivation treatment (Dec-Mar inclusive) 1979-83

<table>
<thead>
<tr>
<th></th>
<th>Undrained</th>
<th>Drained</th>
<th>Drained</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Surface runoff</td>
<td>Surface runoff</td>
<td>Mole-pipe drain</td>
</tr>
<tr>
<td>Cult*1</td>
<td>D.drill*2</td>
<td>Cult*1</td>
<td>D.drill*2</td>
</tr>
<tr>
<td>1979/80</td>
<td>55</td>
<td>-</td>
<td>5</td>
</tr>
<tr>
<td>1980/81</td>
<td>68</td>
<td>56</td>
<td>5</td>
</tr>
<tr>
<td>1981/82</td>
<td>73</td>
<td>83</td>
<td>7</td>
</tr>
<tr>
<td>1982/83</td>
<td>73</td>
<td>89</td>
<td>3</td>
</tr>
</tbody>
</table>

*1 tined 1979/80, ploughed 1980-83 *2 direct drilled

Drainage was continuous over most of the winter period with trickle flows lasting up to several weeks after the cessation of rainfall. The lag time between peak rainfall and peak drainflow was typically 2 to 3 hours for deep cultivations but only $\frac{1}{2}$ to 2 hours with direct drilling (Fig 1). Although peak drainflow rates in tilled soils were similar to other comparable sites in the UK, drainflow in direct drilled soil was often higher, particularly with newly drawn mole channels. Although the difference between peak drainflows under direct drilling and ploughing appeared to be seasonal, examination of the effect over several years showed an average 30% increase (Fig 2). Another important difference observed with direct drilling was that the recession of the drainflow hydrograph was substantially faster (Fig 1).

In conjunction with drainage, the total plot outflow hydrograph under the different cultivation treatments was markedly different. For the event given in Fig 1 the outflow from direct drilled land was 3.4 mm/hr compared to only 1.2 mm/hr from ploughed land.

Mole channel deterioration and soil structure

The primary mode of mole channel failure was the gradual piecemeal collapse of the roof and walls as observed in many heavy clay soils in the UK (Harris 1984). This process occurred equally under both ploughing and direct drilling, in most years. Complete mole channel collapse was observed after 3-4 years and the drained plots were accordingly remoled. However during the period of study several exceptionally dry seasons occurred and caused differential decay of the mole channels under the respective tillage treatments. The first effect was noted after the dry summer of 1983 (Table I) when limited topsoil infill into the mole channel was observed particularly with direct drilling. In a subsequent hot dry spell in June 1986 extensive deep cracking occurred especially on direct drilled drained plots extending from the soil surface to below mole channel depth. Topsoil infill led to the failure of the mole channel
Fig 1. Deep drainflow response for direct drilled and ploughed treatments to a winter rainfall event, January 1982. The mole drainage channels are four years old.

Fig 2. Ratio of direct drilled to ploughed treatment peak drainflow for each runoff event greater than 0.7 mm/hr. Note that in the first two years all plots were tine cultivated, the ratio shown relates only to plots designated to be the respective tillage treatment.
system. In contrast the dry summer of 1984 was followed by extensive mole channel roof collapse on all plots resulting in infill of the original channel. A continuous void up to 50-100 mm diameter was observed in the position of the old roof under direct drilling resulting in an effective but shallower channel zone.

The soil structure in association with the mole drainage channels was better developed under direct drilling with many vertical cracks likely to encourage water movement. Permanent burrowing earthworm populations were low with no consistent difference between tillage treatments.

Drainage design standards

A computer model was developed based on pipe hydraulics and trench parameters to derive the hydraulic head associated with underdrainage pipe systems subjected to drainflows above the UK design standard (MAFF 1982). The model was tested on typical drainflow hydrographs recorded from both ploughed and direct drilled plots at Brimstone Farm to determine if a change in the design standard was necessary. The model showed that substantial surcharging in excess of that normally experienced with cultivations would occur with direct drilling. The effect of this surcharge was firstly to attenuate and delay the hydrograph peak but also resulted in the temporary backup of water in the pipe trench system and soil profile causing frequent but short term submergence of the mole drainage channels. This result was confirmed by data from two plots in which the pipe capacity was restricted to the order of the design standard for the site. No evidence of exaggerated deterioration of mole channels was noted although structural cracking associated with the mole channel may have been reduced. Surcharging of the pipe system up to the ground surface was both predicted by the model and recorded in the field.

DISCUSSION

Runoff from this heavy clay soil was substantially different depending on the depth of cultivation. In conjunction with the removal of residues, surface runoff was both very peaky and frequent with direct drilling particularly on undrained land but also in association with an effective mole drainage system. Similar increased amounts of surface runoff were recorded by Schwab et al (1975) from a flat silty clay soil where residues were also removed. At Brimstone Farm the rapid surface runoff caused small erosion rills, especially on the undrained plots extending from the permanent tramlines. This suggested that in similar conditions shallow cultivations should only be practised in conjunction with an adequate drainage system.

Drainflow was also affected by tillage with removal of excess rainfall being more rapid with direct drilling. Peak runoff was also higher and earlier and recessions were faster. The cause was almost certainly due to the improved structure observed as no difference was found in earthworm populations. Although other workers found higher earthworm counts under direct drilling (Barnes and Ellis 1979), it is important to note that most of their work related to spring grown crops rather than the autumn sown crops associated with Brimstone Farm.

The better structure observed improved the effectiveness of the mole channel system (Fig 1). However concern must be expressed that the improved structure with direct drilling could lead to rapid failure
resulting from infill of both cracks and mole channels by topsoil. This mode of failure was also cited by Goss et al (1984) to explain poorer watertable control experienced in one year with direct drilling on a site with the same soil series.

The runoff results suggest that the underdrainage pipe size requirement of clayland subject to simplified cultivation systems is higher if full advantage is to be made of the improved removal of excess water noted. For such cultivations utilisation of the lower drainage design standard developed from and applicable to ploughed land will result in very substantial surcharge within the trench system. Damage to the mole drainage system may be limited to a deterioration in associated structure but if surcharge extends to the soil surface the potential problem of surface runoff and erosion will be exacerbated.

CONCLUSION

(1) Although direct drilling gave rise to higher surface runoff than deep cultivations, more rapid vertical movement of water also occurred through the subsoil.

(2) Interaction with the underdrainage system resulted in a peakier drainflow hydrograph which could cause substantial surcharging of the pipe drains and cause water to back up in the pipe trench for drainage systems designed for ploughed land.

(3) The deterioration of the mole channel system was notably affected by weather patterns; infill of cracks by topsoil could be a problem under direct drilling.

REFERENCES


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EXPERIMENTS ON THE GROWING OF CEREALS WITH DIFFERENT TILLAGE SYSTEMS IN CENTRAL SPAIN.

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ABSTRACT

The present paper summarizes the experience acquired in Central Spain in the last years with the techniques of minimum tillage and direct drilling on the growing of cereals. It also focuses the main drawbacks which hamper adoption of the latter technique.

On the other hand, the results obtained in the first experiment carried out in Central Spain with direct drilling (1980-84) are given in terms of soil bulk density, soil moisture content, crop establishment, crop yields, and energy requirements. In this first experiment three ways of carrying out direct drilling (i.e. Direct drilling in standing stubble; Direct drilling in stubble without straw; and direct drilling in burnt stubble) were compared to conventional tillage on the growing of winter wheat and spring barley.

INTRODUCTION

Research and experimentation with direct drilling and minimum tillage techniques started in Spain in the late 70s. The first two goals of the research conducted were the assessment of the crop growth and crop yields under these two tillage techniques, in comparison to conventional tillage, and the knowledge of their advantages and disadvantages.

On the long term is another third goal which is the assessment of the techniques in relation to their effectiveness in soil erosion control (Monleón, 1986).

Nowadays the average acreage devoted to direct drilling on the growing of cereals reaches 6000 ha, mainly located in the province of Lérida (in the North East of Spain). Very little information is available about the acreage devoted to minimum tillage because this technique is widely adopted by the farmers whenever the climatic conditions are such that the total available sowing days are reduced.

The main reason why there exists a minimum surface area designated for cultivation on direct drilling, is the scarce agricultural spreading that existed between farmers. There existed other reasons as well, not least, the following:

1. Lack of confidence in the substitution of the moldboard plough for an application of a herbicide

2. The reduced market in Spain for machines for direct drilling and their high purchase cost. Their price is four or five times higher that a conventional drill.
3. Surface residues (stubble and straw) cause severe problems to cover the seeds with soil. Nevertheless, in those areas where direct drilling has been adopted in the growing of both cereals and sunflower, farmers have observed that:

1. There is not crop yield reduction with this technique and in some cases there is an increase in crop yields (Giráldez et al 1985).

2. Running cost do not increase, although they are strongly dependent on the total amount of chemicals required for weed control (Hernanz, 1988).

3. Labour and timeliness costs are reduced. There is more time available for sowing in the proper moment and it can also be carried out earlier (S. Girón, 1987).

EXPERIMENTS WITH DIRECT DRILLING ON THE GROWING OF WINTER WHEAT AND SPRING BARLEY IN CENTRAL SPAIN.

MATERIALS AND METHODS

This work gives the obtained results from the first experiment that took four years to complete (1980-84). This consisted in comparing three different forms of soil covering by direct drilling, with conventional tillage performed by farmers of the area. The treatments involved were:

L₁ - Conventional tillage (i.e. mouldboard ploughing and secondary tillage)
L₂ - Direct drilling on standing stubble
L₃ - Direct drilling on stubble without straw
L₄ - Direct drilling on burnt stubble

Field trials were conducted at El Encín Research Station, on a soil where characteristics are summarized in Table I.

Crop rotation was winter wheat followed by spring barley during three consecutive years. Prior to seeding direct drilled plots were sprayed with paraquat (0.8 l/ha). All the treatments were postemergence sprayed with ioxynil + mecoprop (0.3 + 0.9 l/ha). The treatments were arranged in a complete randomized block design with three replications.

OBJECTIVES

Some of the objectives of this experiment were:

- The assessment at different depths of the soil bulk density and the gravimetric soil moisture content.
- The comparison of the crop establishment and crop yields.
- The evaluation of the energy requirements of the treatments considered.

RESULTS AND DISCUSSION

Figure 1. shows the evolution of the soil bulk density and the gravimetric soil moisture content at depths of 10,
20, 25, 30 and 40 cm. On the direct drilling plots soil bulk density is stabilized around 1.6 g/cm³. The differences in soil bulk density encountered in the conventional tilled plots were reduced along the growing season just after the seedbed tillage practices were carried out. These differences were less as soil depth increased. Soil bulk density values for the tilled plots did not reach the values encountered in the direct drilled plots, although at the end of each growing season no statistical difference was observed. In all the treatments gravimetric soil moisture content changed very little with soil depth. In general, the tilled plots had higher soil moisture contents but just only in June 1982 the differences were statistically significant.

Tables II and III summarizes the values encountered for crop establishment and crop yields in the four years considered. In the first three growing seasons, no statistical difference was observed among the crop establishment in the four treatments compared. In the fourth growing season conventional tillage resulted in the lowest crop establishment.

No statistical difference was encountered among the crop yields obtained with all the treatments compared. Both in 1982 and 1983 the first of these two years sowing was delayed too much and very high temperatures were reached before crop ripening, whereas the second year was very drought being the total rainfall during the growing season 81 mm. The highest crop yields were obtained in 1984. These yields were due both to the high amount of rainfall, in the growing season, and the eveness of its distribution.

Energy inputs and energy efficiency in the last tillage treatments compared are summarized in Table IV. Just only the energy inputs required for total crop production are considered. If the energy associated to seed and fertilizer are taken into account, direct drilling resulted in an energy saving of 10% in comparison to conventional tillage. Both seed and fertilizer account 80% and 90% of the total energy required by direct drilling and conventional tillage, respectively. In terms of fuel savings, direct drilling saved an 80% of the fuel consumed by conventional tillage.

CONCLUSIONS
1. Gravimetric soil moisture content was the same in all the treatments compared.
2. Soil compaction in the tilled plots reached the same values as in the direct drilled plots at the end of each growing season.
3. Crop yields were the same in all the treatments compared - and their values were affected by the amount of rainfall during the growing season and the eveness of its distribution.
4. When seed and fertilizer is considered in the energy balance, direct drilling resulted in no more than 10% of energy saving in comparison to conventional tillage.
REFERENCES

- Giráldez et al., 1985. Laboreo mínimo y siembra directa en los suelos arcillosos de la campiña andaluza. II Jornadas - Técnicas del Cereal ITGC. Pamplona. 77-93.


<table>
<thead>
<tr>
<th>Soil depth (cm)</th>
<th>Particle size</th>
<th>Organic matter</th>
<th>Standard Proctor Compaction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sand %</td>
<td>Silt %</td>
<td>Clay %</td>
</tr>
<tr>
<td>0 - 20</td>
<td>18.7</td>
<td>61.8</td>
<td>19.5</td>
</tr>
<tr>
<td>20 - 40</td>
<td>32.3</td>
<td>49.1</td>
<td>18.6</td>
</tr>
</tbody>
</table>

Table II. Crop establishment (Plants/m²)

<table>
<thead>
<tr>
<th>GROWING SEASON</th>
<th>TREATMENTS</th>
<th>S. E.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L₁</td>
<td>L₂</td>
</tr>
<tr>
<td>1980-81</td>
<td>282 a</td>
<td>302 a</td>
</tr>
<tr>
<td>1981-82</td>
<td>406 a</td>
<td>344 a</td>
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<tr>
<td>1982-83</td>
<td>271 a</td>
<td>330 a</td>
</tr>
<tr>
<td>1983-84</td>
<td>303 a</td>
<td>404 b</td>
</tr>
</tbody>
</table>

Figures in the same row followed by the same letter are not significantly different.
Fig. 1. - Evolution of soil properties. Soil Bulk Density (SBD) and Gravimetric soil Moisture content (GSMC), (1980-1984).

----- Tilled plots

Untilled plots. Average of the three treatments.
Table III. Crop yields (kg/ha 15% d.m.)

<table>
<thead>
<tr>
<th>GROWING SEASON</th>
<th>TREATMENTS</th>
<th>SEASONAL RAINFALL (mm)</th>
<th>Crop</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L₁</td>
<td>L₂</td>
<td>L₃</td>
</tr>
<tr>
<td>1980-81</td>
<td>1828a</td>
<td>1512a</td>
<td>1835a</td>
</tr>
<tr>
<td>1981-82</td>
<td>1108a</td>
<td>1145a</td>
<td>1102a</td>
</tr>
<tr>
<td>1982-83</td>
<td>832a</td>
<td>755a</td>
<td>654a</td>
</tr>
<tr>
<td>1983-84</td>
<td>2268a</td>
<td>2455a</td>
<td>2763a</td>
</tr>
</tbody>
</table>

Table IV. Energy consumption and efficiency

<table>
<thead>
<tr>
<th>GROWING SEASON</th>
<th>ENERGY CONSUMPTION (MJ/ha)</th>
<th>ENERGY EFFICIENCY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CONVENTIONAL TILLAGE</td>
<td>DIRECT DRILLING</td>
</tr>
<tr>
<td></td>
<td>CONVENTIONAL TILLAGE</td>
<td>DIRECT DRILLING</td>
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<tr>
<td>1980-81</td>
<td>13945</td>
<td>12507</td>
</tr>
<tr>
<td>1981-82</td>
<td>13203</td>
<td>11715</td>
</tr>
<tr>
<td>1982-83</td>
<td>13626</td>
<td>12305</td>
</tr>
<tr>
<td>1983-84</td>
<td>13203</td>
<td>11882</td>
</tr>
</tbody>
</table>

Figures in the same row followed by the same letter are not significantly different.
SOIL WATER AND TEMPERATURE REGIMES UNDER TILLAGE AND COVER CROP MANAGEMENT FOR VEGETABLE CULTURE

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ABSTRACT

Selected vegetables were grown under three tillage regimes (conventional tillage, strip-tillage (subsoil-coultor combination), and no-tillage) or strip-tillage with various cover crop residue. Grass residue treatments resulted in greater soil water content than legume residue or non-residue surfaces. Cover residue or mulch reduced soil temperatures at 10 cm depth below bare or cultivated treatments. Tillage reduced soil water content in the 0-10 cm depth below that of no-tilled or between-row strip-tilled soils. Tillage treatments produced warmest soil temperatures in the between-row cultivated locations. Lowest soil temperatures were in the no-till treatments.

INTRODUCTION

Conservation tillage has become an accepted cultural practice for many seeded row crops since its introduction in the 1950's. Acceptance can be attributed to a combination of events occurring concurrently including herbicide development and use, concern for soil erosion, and innovative equipment modifications. Horticultural crops have not been researched as aggressively as grain crops in conservation tillage experiments (Standifer and Beste, 1985). The beneficial value of surface residues or mulch in conserving soil moisture in horticultural crops has been known for many years (Emerson, 1903) with materials such as black plastic emulating the benefits of crop residues (Estes et al., 1985). Increased use of cover crops in conservation tillage in the United States has resulted in soil water conservation, biological nitrogen additions and decreased sediment loads from cropped fields (Hoyt and Hargrove, 1986).

The introduction of a no-till transplanter has provided a means for planting bare rooted or containerized transplants in undisturbed soil (Morrison et al., 1973). Direct seeded vegetables (sweet corn (Zea Mays), dry beans (Phaseolus spp.), squash (Cucurbita spp.), etc.) can be easily planted by current no-till planters designed for agronomic row crops [corn, soybean (Glycine max L.), etc.] This offers an alternative cultural technique to conventional planting. Prior no-till experiments with vegetables have resulted in various degrees of success depending on location, year, moisture, and other factors. Tillage experiments in Oregon resulted in greater sweet corn yields with conventional-tillage than with no-tillage or strip-tillage culture (Petersen et al., 1986). Warmer soil temperatures at planting in the conventional tillage soil contributed to the higher yields even though temperature differences among treatments diminished with time. Conversely, in Kentucky, Knavel et al., (1977) obtained greater sweet corn and popcorn yields (Knavel et al, 1985) with no-till culture than with conventional-tillage. This
paper describes soil water and temperature changes associated with the various tillage and cover crop options available for vegetable production.

MATERIALS AND METHODS

Field experiments were established in 1984 and 1985 to measure the effects of tillage or winter cover residue with strip-tillage on winter squash, sweet corn, tomatoes (Lycopersicon esculentum Mill.), cabbage [Brassica oleracea (L.) Capitata group], potatoes (Solanum tuberosum L.), and snap beans grow under soil and climate conditions inherent to the mountain region of North Carolina (elevations of 700-1200 meters). The soil was a Delanco loam, a fine loamy, mixed, mesic Aquic Hapludult.

Sweet corn and snap-beans tillage experiment:

Three tillage treatments were established in the following manner: conventional-tillage entailed a spring mold board plowing followed by roto-tilling the entire surface before planting. Strip-tillage was established by running an in-row subsoiler-coulter combination (Bush Hog Ro-till) through the rows before planting. No-tillage consisted of planting only with a no-till planter (Allis-Chalmers no-till planter). All treatments were planted with the no-till planter at the same time. Care was taken to seed all treatments within crops at the same depth. Strip-tillage and no-till culture both had a fall planted barley (Hordeum vulgare L.) cover crop (6000 kg/ha dry matter) desiccated with paraquat (1,1'-dimethyl-4,4'-bipyridinium salts) 10 days before planting.

Strip-tillage cover crop residue experiments:

Tomatoes and potatoes were subjected to strip-till culture and various grass and legume cover crops as residue treatments. All cover crops were fall planted at recommended rates and grown until spring. Two weeks before transplanting the cover crops were measured for biomass and desiccated. Within one day of transplanting, strip-till culture was created by the in-row subsoiler-coulter combination (Bush Hog Ro-till) and the specific crop hand transplanted in the cultivated zone.

Surface applied herbicides were either broadcast over the top after transplanting or banded between the rows with a shielded sprayer. All experiments received nitrogen, phosphorous, or potassium fertilizer according to soil test recommendations. Soil temperatures were measured with a Digi-Sense thermistor thermometer on selected dates. All temperatures reported were taken at a soil depth of 10 cm during the warmest part of the day (1pm to 3pm). All temperature readings were made in triplicate per treatment with four replications per residue or tillage treatment. Soil moisture was measured gravimetrically from a 0-10 cm core sampled from each treatment soil (4 replications per treatment).

RESULTS

Water relations: Cover residues strip-till:

Soil water measurements from the three seeded vegetable crop fields showed that, in general, conventional tillage treatments reduced soil water contents lower than strip-till or no-till treatments (Table I).
Soil water measurements in the cultivated in-row area (IR) of the strip-till treatment for June 13 were lower than in the between-row areas (BR), and were similar to soil water measurements in the IR area of the conventional-tilled treatment. Throughout the summer, soil water measurements continued to be lower in the in-row location than the between-row location for the strip-till treatment. Likewise, soil water content in the between-row location for strip-till and no-till between-row locations reported similar water measurements. These measurements should be similar since equal quantities of residue covered the surface of each between-row location. Conventional-tillel soil water measurements in the between-row area were significantly lower than the strip-till or no-till between-row location measurements in all but one sample period (July 11). Plant water uptake was evident by the similar soil water measurements among the three tillage treatments taken in the in-row location for sweet corn and snapbeans on June 25 and July 11.

In general, cover residue in field plots of strip-till potatoes enhanced soil water measurements over bare or cultivated soil (Table II). Soil water measurements in May (before potato planting) showed rye residue soils with greatest water of all residue treatments and hairy vetch (Vicia villosa Roth) residue soils slightly higher in soil moisture than crimson clover residue treatments. Cultivated soil treatments produced water contents in May and throughout the summer that were greater than bare soil water measurements. Soil water measurements after tillage (June and July sample periods) showed grass residues with greater soil water content than legume residue or non-residue soils. Rainfall preceding the June 27 sample period recharged soil water and produced high and similar soil water measurements among treatments.

Soil Temperature: Cover residue strip-till

Field plots of strip-tilled tomatoes with various cover residue showed a soil warming effect from treatments without residue (Table III). Adding a mulch cover (equivalent to 4000 kg dry matter/ha) dropped soil temperatures the lowest of all cover treatments. Rye and ryegrass residue treatments both cooled soil temperatures slightly lower than legume residue (for most days measured) and both legumes were also below soil temperatures of the non-covered soils (bare and cultivated).

Soil Temperature: Tillage

The three tillage management systems produced variations in soil temperatures that were related to the residue left on the surface or incorporated by cultivation (Table I). Warmest soil temperatures were in the conventional-tilled between-row location where sunlight had direct contact with the soil. These higher soil temperatures in the conventional between-row location continued throughout the growing season for all three vegetable crops. Lowest soil temperatures among the three tillage management systems were the no-till between-row locations for sweet corn and no-till in-row location for bush beans. Strip-till between-row soil temperatures were the same or statistically no different from the no-till between-row location soil temperatures for eight out of nine days recorded. In-row strip-till soil temperature readings (where cultivation occurred) were more similar to in-row conventional-tilled locations than between-row strip-till locations for the seven of nine days recorded.
The following conclusion can be drawn from the soil water content and temperature readings taken from various vegetable cultures and subjected to tillage and cover crop strip-till treatments.

1. Soil water measurements after cover crop desiccation, tillage, and summer crop planting showed grass residue with greater soil water content than legume or non-residue soil.

2. Soil temperatures early in the vegetable crop growing season were lowered by cover residue or mulch below the bare or cultivated treatment temperatures.

3. Tillage reduced soil water content in the 0-10 cm depth below that of no-tilled or between-row strip-tilled soils.

4. Tillage treatments produced warmest soil temperatures in the between-row cultivated locations for the seeded crops; lowest soil temperatures were in the no-till treatments.

5. Both plant shading late in the growing season and cover residue reduced heat gain for the in-row location in the tillage experiments.

LITERATURE CITED


Table I. Soil water and temperature regimes for tillage treatments, 1985.

<table>
<thead>
<tr>
<th>TILLAGE</th>
<th>Sweet Corn</th>
<th></th>
<th></th>
<th></th>
<th>Bush Beans</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>June 13</td>
<td>June 21</td>
<td>June 25</td>
<td>July 11</td>
<td>June 13</td>
<td>June 25</td>
<td>July 11</td>
<td></td>
</tr>
<tr>
<td></td>
<td>TR</td>
<td>BR</td>
<td>TR</td>
<td>BR</td>
<td>TR</td>
<td>BR</td>
<td>TR</td>
<td>BR</td>
</tr>
<tr>
<td>Conventional</td>
<td>.120*</td>
<td>.115</td>
<td>.107</td>
<td>.106</td>
<td>.112</td>
<td>.117</td>
<td>.109</td>
<td>.137</td>
</tr>
<tr>
<td>Strip till</td>
<td>.132*</td>
<td>.170</td>
<td>.118</td>
<td>.163</td>
<td>.116</td>
<td>.179</td>
<td>.125</td>
<td>.167</td>
</tr>
<tr>
<td>No-till</td>
<td>.172*</td>
<td>.175</td>
<td>.131</td>
<td>.136</td>
<td>.128</td>
<td>.156</td>
<td>.112</td>
<td>.166</td>
</tr>
<tr>
<td>LSD (.05)</td>
<td>.010</td>
<td>.033</td>
<td>NS</td>
<td>.030</td>
<td>NS</td>
<td>.033</td>
<td>NS</td>
<td>.027</td>
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<table>
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<th>June 25</th>
<th>July 3</th>
<th>June 13</th>
<th>June 25</th>
<th>July 17</th>
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<tr>
<td></td>
<td>TR</td>
<td>BR</td>
<td>TR</td>
<td>BR</td>
<td>TR</td>
<td>BR</td>
</tr>
<tr>
<td>Conventional</td>
<td>25.8*</td>
<td>30.2</td>
<td>30.9</td>
<td>34.3</td>
<td>21.4</td>
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</tr>
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<td>Strip-till</td>
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<td>24.6</td>
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<td>26.4</td>
<td>21.3</td>
<td>21.0</td>
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<tr>
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<tr>
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<td>.8</td>
<td>1.0</td>
<td>1.3</td>
<td>.8</td>
<td>.3</td>
<td>.6</td>
</tr>
</tbody>
</table>

- *Soil water content for a 0-10 cm depth sample.
- *Soil temperature measurements at 10 cm depth.
- *Air temperature measurements taken over a 24 hour period.
- IR = in plant row; BR = between plant rows

<table>
<thead>
<tr>
<th>May</th>
<th>June</th>
<th>July</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air maximum</td>
<td>26.7*</td>
<td>22.8</td>
</tr>
<tr>
<td>Air minimum</td>
<td>8.9</td>
<td>11.1</td>
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</tbody>
</table>
Table II. Cover crop residue effect on soil water content in strip-till potatoes, 1984.

<table>
<thead>
<tr>
<th>Cover residue</th>
<th>May</th>
<th>June</th>
<th>July</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5</td>
<td>14</td>
<td>1</td>
</tr>
<tr>
<td>Bare</td>
<td>.231</td>
<td>.199</td>
<td>.193</td>
</tr>
<tr>
<td>Cultivated</td>
<td>.273</td>
<td>.284</td>
<td>.204</td>
</tr>
<tr>
<td>Crimson Clover</td>
<td>.299</td>
<td>.253</td>
<td>.205</td>
</tr>
<tr>
<td>Hairy Vetch</td>
<td>.311</td>
<td>.287</td>
<td>.194</td>
</tr>
<tr>
<td>Barley</td>
<td>.314</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ryegrass</td>
<td>.308</td>
<td>.288</td>
<td></td>
</tr>
<tr>
<td>Wheat</td>
<td>.317</td>
<td>.287</td>
<td>.230</td>
</tr>
<tr>
<td>Rye</td>
<td>.323</td>
<td>.310</td>
<td>.238</td>
</tr>
<tr>
<td>LSD (.05)</td>
<td>.038</td>
<td>.064</td>
<td>.029</td>
</tr>
</tbody>
</table>

*Soil moisture for a 0-10 cm depth sample taken between crop rows.

Table III. Cover crop residue effect on soil temperatures in strip-tillage tomatoes, 1984.

<table>
<thead>
<tr>
<th>Cover Residue</th>
<th>June</th>
<th>July</th>
<th>August</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>8</td>
<td>25</td>
<td>6</td>
</tr>
<tr>
<td>Bare</td>
<td>24.0*</td>
<td>25.8</td>
<td>27.0</td>
</tr>
<tr>
<td>Cultivated</td>
<td>23.2</td>
<td>25.8</td>
<td>26.9</td>
</tr>
<tr>
<td>Hairy Vetch</td>
<td>22.5</td>
<td>24.5</td>
<td>26.3</td>
</tr>
<tr>
<td>Crimson Clover</td>
<td>22.5</td>
<td>24.2</td>
<td>25.6</td>
</tr>
<tr>
<td>Rye</td>
<td>22.4</td>
<td>23.3</td>
<td>25.3</td>
</tr>
<tr>
<td>Ryegrass</td>
<td>21.6</td>
<td>23.1</td>
<td>25.1</td>
</tr>
<tr>
<td>Mulch</td>
<td>20.7</td>
<td>22.3</td>
<td>23.4</td>
</tr>
<tr>
<td>LSD (.05)</td>
<td>1.0</td>
<td>1.3</td>
<td>.6</td>
</tr>
<tr>
<td>Air Max</td>
<td>31.1*</td>
<td>25.6</td>
<td>28.3</td>
</tr>
<tr>
<td>Air Min</td>
<td>14.4</td>
<td>15.0</td>
<td>17.2</td>
</tr>
</tbody>
</table>

*Soil temperature measurements at 10 cm depth.
*Air temperature measurements taken over a 24 hour period.
EFFECTS OF SOIL MANAGEMENT TREATMENTS ON SOIL PHYSICAL CONDITIONS AND FRUIT PRODUCTION IN A CITRUS ORCHARD OF W. SPAIN.

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¹ Instituto Valenciano de Investigaciones Agrarias.
² Sección de Mecanización Agraria, Universidad Politécnica de Valencia.

ABSTRACT

A number of soil management systems have been tested in citrus culture, comparing several conventional systems (rotary tiller, spading machines, and cultivator) with minimum tillage and non-tillage.

The non-tillage systems reduce rate of water penetration to values of 10-15 cm/h, producing an increase in bulk density and compaction, and obliging to make some modifications in the irrigation systems.

The results show an increase in production with minimum tillage and non-tillage (winter cover) and no variation in fruit quality properties concerning any cultivation systems.

INTRODUCTION

The citrus growing areas of Valencia (Spain) have quite specific conditions, because of their small size, for mechanical operations, and particularly for the soil management methods. In this regard, many cultivation practices and implement combinations are being used, according to the personal criteria of the grower, or the traditional uses in each area.

The non-tillage methods in citrus appear to considerably reduce water infiltration capacity, either from compactation of the cultivation profile, or from build-up of a superficial crust (Pomares, 1975). This reduction in the infiltration ability must be balanced with a greater frequency of irrigation, or with the establishment of crosswise barriers on the irrigation lines increasing the time that water remains on the soil (Juste et al., 1985).

Concerning fruit production and quality obtained with the different cultivation systems, the results are contradictory. Jones et al., 1961 report higher yields in Washington Navel using non-tillage systems. Similar results were obtained by Cary and Evans (1972) in a experiment with various systems of non-tillage over 21 years. Conversely, Rodriguez and Moreira, 1964 obtain in Brazil higher yields with soil mulching and artificial padding.

MATERIALS AND METHODS

Cultural practices

Field experiments were conducted on a 21 year-old citrus orchard during
the 1983-85 period at the experimental fields of the Instituto Valenciano de Investigaciones Agrarias on the Valencia region (Spain) on a plot of 0.9 ha planted with trees of the Washington Navel variety, with a spacing of 6 m. The soil had been under cultivation prior to the application of the soil management treatments, and one year before the initiation of the experiment, was made a sub-soiling in the centre of the roads at 25 cm depth.

In this region, there is an arid climate with average annual rainfall of 358 mm. Generally, pan evaporation exceeds that of rainfall except for some autumn-winter months. For the rest of the year it is necessary to irrigate using a total 800-900 mm of water. Flooding of roads between trees was the irrigation method used. This study was carried out on a sandy loam soil with characteristics as shown in Table I.

Table I. Characteristics of experimental soil.

<table>
<thead>
<tr>
<th>Horizon depth (cm.)</th>
<th>Organic Matter (%)</th>
<th>Sand (%)</th>
<th>Silt (%)</th>
<th>Clay (%)</th>
<th>Bulk density (Mg m^-3)</th>
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</thead>
<tbody>
<tr>
<td>0-10</td>
<td>1.46</td>
<td>64.40</td>
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<td>19.27</td>
<td>1.47</td>
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<td>10-20</td>
<td>1.30</td>
<td>65.93</td>
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<tr>
<td>20-30</td>
<td>1.14</td>
<td>67.27</td>
<td>13.97</td>
<td>18.77</td>
<td>1.69</td>
</tr>
</tbody>
</table>

Experimental design.

Six cultivation treatments were tested in three replicates. Each sub-plot was 483 m^2 corresponding to a line of trees 92 x 5.25 m.

The treatments applied were as follows:

**T1:** Non-tillage on bare soil throughout the year: bare soil is maintained by applications of residual herbicide (Diuron + Bromacil) in the irrigation water, and dosages of 8 Kg/ha.

**T2:** Minimum tillage with one or two spading machine runs in spring, and over the rest of the year weed was controlled by two application of Paraquat at 0.5 Kg/ha.

**T3:** Non-tillage with winter cover. In this treatment weed was controlled in spring as in T2, but with three applications.

**T4:** Tillage over the whole period using rotary tiller.

**T5:** Tillage over the whole period, with spading machine.

**T6:** Traditional cultivation; one or two runs of spading machine in the spring, and later using rotary tiller and cultivator.

Soil measurements.

Bulk density was determined down to 25 cm in 5 cm depth increments using 197.9 cm^3 metal cores (6 cm ID and 7 cm high), making 4 replications per treatment.
Water content: soil samples for the determination of water content, for cone resistance and vane shear strengths were obtained by augering.

Infiltration capacity was measured with a 30 cm double-ring infitrometer using 2 cm head of water for 1 h period and making 4 replications per plot.

Cone resistance was measured with a hand held penetrometer. The readings were taken 1 day after reaching field capacity to a depth of 35 cm.

Crop measurements Fruit quality tests were conducted using chemical analyses of juice and physical indexes. Three replications were made per treatment from three trees each, using 25 fruits per replication taken from all the parts of the trees. Yield was evaluated in each treatment.

RESULTS AND DISCUSSION

Dry bulk density.

The bulk density was measured in all cases, two irrigations after tillage, meaning that the effects of tillage were already slightly reduced.

In Fig. 1 is shown the bulk density variation in the summer on the third year of the experiment for the various treatments. TX represents the mean values of the T4, T5 and T6.

Fig. 1. Bulk density variation

![Bulk Density Variation](image)

Apparent density with tillage treatments appears to be approximately 0.1 Mg/m³ lower. From the rest of treatments, minimum tillage is slightly lower than those of non-tillage.

Nevertheless, the readings showed high variability due to the presence of a high concentration of gravel and coarse particles in the soil. This high proportion of coarse elements has been enhanced by the irrigation system used that caused to carry away the fine particles from the plot head to the end. As shown in Table II, this increase was considerably higher in the tilling treatments.
TABLE II. Changes in soil bulk density and particle size distribution in the 0-10 cm layer at different times.

<table>
<thead>
<tr>
<th>Soil property</th>
<th>Initial data 1983</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>TX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravel</td>
<td>7.80</td>
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<td>9.50</td>
<td>9.87</td>
<td>12.86</td>
</tr>
<tr>
<td>% Final row</td>
<td>2.10</td>
<td>2.28</td>
<td>2.63</td>
<td>1.13</td>
<td>3.16</td>
</tr>
<tr>
<td>Bulk density (Mg m⁻³)</td>
<td>1.47±0.05</td>
<td>1.65±0.04</td>
<td>1.62±0.03</td>
<td>1.66±0.07</td>
<td>1.54±0.05</td>
</tr>
</tbody>
</table>

Water content,

Fig. 2 shows the water content in soil (g/100 g) for the different treatments, before and after irrigation at two depths (5 and 25 cm). It was observed that there were appreciable differences between the non-tillage treatments (T1 and T3) and the tillage and minimum tillage on surface. In depth, the water content after irrigation is smaller in the tillage and minimum tillage treatments, and was maintained in those of non tillage.

Fig. 2. Soil water content.

Infiltration capacity,

In figures 3a, 3b, are shown the changes in water infiltration rate for the different tillage methods in the winters of 1984, and 1986. The treatments of non-tillage have a lower infiltration than those of tillage and minimum tillage. Throughout the experiment, the infiltration has gradually decreased in the tillage treatments, until becoming similar than that in minimum tillage.
Figure 4 shows the cone resistance under different methods, after being measured at the beginning of spring and at the end of summer, 72 h after irrigation. It appears that cone resistance is much lower, in all cases, in spring than in summer. In non-tillage (T1, T3), down to 12 cm depth, it is markedly higher than in tilled soils. The minimum tillage treatment (T2) appears as intermediate, and the superficial layer of the soil is less compacted throughout the summer than in the non-tillage treatments.

Fig. 4. Cone resistance (M Pa) under different tillage methods: a) spring 1984; b) summer 1985.

Crop measurement.

Table III shows diameters and yields from each treatment along the three years experiment. Minimum tillage (T2) appears to reduce fruit size throughout the experiment, however, the yields are consistently the highest.

In 1984 fruit sizes and weights were lower than the standards in all the area, which suggests that the results obtained that year could be attributed to failures in the management systems used.

Concerning rind thickness and fruit density, there were no significant
differences, but there was a slight tendency for the fruit to colour ahead, in the tilling treatments.

**TABLE III. Diameter and yields from each treatment along the three years.**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Diameter (mm)</th>
<th>Production (kg/tree)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>76.5</td>
<td>74.7</td>
</tr>
<tr>
<td>T2</td>
<td>74.1</td>
<td>74.8</td>
</tr>
<tr>
<td>T3</td>
<td>76.7</td>
<td>71.9</td>
</tr>
<tr>
<td>T4</td>
<td>78.9</td>
<td>71.0</td>
</tr>
<tr>
<td>T5</td>
<td>74.1</td>
<td>64.9</td>
</tr>
<tr>
<td>T6</td>
<td>76.5</td>
<td>70.6</td>
</tr>
<tr>
<td>T7</td>
<td>77.2</td>
<td>70.5</td>
</tr>
</tbody>
</table>

* In each column, means followed by a common letter are not significantly different at the 5% level, DMRT.

**CONCLUSIONS**

- The non-tillage system on bare soil brings about serious problems of water infiltration because the high compactation degree, which entails a reduction in yields.

- The non-tillage system with winter cover provides better results in yield, even though the physical properties of the soil and the water movement are similar to the previous one.

- It appears that, from this study, the minimum tillage (T2) affords an excellent potential in this region, since the best yields have been obtained under this method, which is explainable because the soil and water movement are similar to those obtained with any of the tillage systems.

**REFERENCES**


RESULTS FROM LONG-TERM EXPERIMENTS WITH AGRICULTURAL CROPS MEASURING THE EFFECTS OF VARIOUS AMOUNTS OF NITROGEN AND DIFFERENT TILLAGE SYSTEMS ON YIELD AND NITROGEN MINERALISATION OF SOIL

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ABSTRACT

A soil tillage experiment running since 1973 was carried out in order to study the influence of different soil mineralisation and yield response of agricultural crops. Tillage was varied by using conventional plow (tilling depth 35 cm) and cultivator (tilling depth 15 cm). Seedbed was prepared by rotary harrow or rotary hoe. Soil properties (density, permeability, organic matter) after reduced tillage led to positive yield response of winter cereals, but to negative response to spring cereals and sugar beets comparing with yields after conventional tillage. Interaction between yield response N-fertiliser-amount, soil tillage and duration of experiment was observed.

INTRODUCTION

Reduction of tilling depth leads to recompaction to the upper soil layer, improvement of permeability in the root-restricting pan below the plowing depth and to an increase of organic matter in the surface soil. The changed soil properties after reduced tillage influence the mineralisation of organic matter and the N-supply of soil (Baeumer, 1980; Doran, 1980; Capelle and Baeumer, 1984; Kitur et al., 1984 and Knittel et al., 1985).

The aim of this experiment was to find out the optimal amount of nitrogen applied to reduced tillage vs. conventional tillage. In addition one would expect a different yield response to crops with duration of the experiment, when the mineralisation behaviour of soil has reached a balance after reduction of tillage intensity.

MATERIALS and METHODS

The experiment was conducted on a sandy loam (alfisol) with good soil structure. At this region (Palatinate) the average amount of rainfall is 560 mm, the average temperature 9.8 °C. Since 1973 the conventional tillage method has been performed by plow (depth 35 cm), the reduced tillage by cultivator (depth 15 cm). After harvest primary tillage was conducted by plow or cultivator. The seed bed was normally prepared with a rotary harrow just before seeding. Between harvest and planting intercropping was performed in order to cover the soil surface. The crop rotation used was: sugar beets - winter wheat - spring barley - oats - maize - winter wheat and winter barley. Chemical weed control was applied annually, if necessary a total herbicide (Glyphosate) against queckgras was used. Four different N-fertiliser-rates were applied in a randomized block design with four replications on conventional and reduced tillage plots. N-amount varied in steps of 30 - 40 kg/ha N, depending on demand of crop. The first dressing in spring or just before sowing was varied, further rates were applied to all treatments. The first rate based on N-amount mineralised in soil.

Samples were taken in February for winter crops and in March for the spring crops. NO₃-content was measured in three layers (0 - 30,
RESULTS and DISCUSSION

The response to N-fertiliser showed two typical curves which were influenced by soil tillage (figure 1). Winter wheat on plowed plots reached the optimum yield at 50 kg/ha N. After reduced tillage the optimum was at 80 kg/ha N. Below the optimum, plots of reduced tillage resulted in yield losses of -0.44 t/ha to -0.28 t/ha. With increasing amounts of N the differences were diminished and changed to positive yield response of 0.36 t/ha at the highest N amount.

Figure 1: Influence of N-amount on the yield of winter wheat after different soil tillage

A quite different response curve was observed for sugar beets (figure 2). The yield difference caused by tillage was -2.08 t/ha to 1.01 t/ha. A deeper tillage prepared a better soil structure for sugar beets than the reduced tillering depth after cultivator. Here the nitrogen application could only reduce the disadvantage, but did not compensate as it happened for winter wheat.

The change from deep plowing to shallow cultivation influenced the balance of mineralisation and microbial activity in the soil. We could expect a N-fixing process in the soil. Since after reduced tillage greater amounts of organic material is incorporated in the upper layer of soil due to the wider C:N ratio of straw. If the change of soil tillage were in balance, we could expect a positive yield response.

For winter cereals (wheat and barley) this balance has been reached in 1983 (table 1). The negative yield response caused by reduced tillage positive response of 0.19 t/ha in 1983 and 0.45 t/ha in 1985. For spring wheat and sugar beets the balance has not been reached until 1987 or other negative changes would influence the growth of these crops.
Figure 2: Influence of amount of N on the yield of sugar beets after different soil tillage.

Table 1: Yield difference (t/ha) between reduced tillage and conventional tillage for agricultural crops at the optimal N-rate ($N_2$)

<table>
<thead>
<tr>
<th>year</th>
<th>crop</th>
<th>w.-cereals</th>
<th>s.-cereals</th>
<th>sugar-b. maize</th>
</tr>
</thead>
<tbody>
<tr>
<td>1977</td>
<td>sugar beets</td>
<td>-0.81</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1978</td>
<td>w.-wheat</td>
<td>-0.28</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1979</td>
<td>s.-barley</td>
<td>-1.13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1980</td>
<td>s.-oats</td>
<td>-0.25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1981</td>
<td>maize</td>
<td></td>
<td></td>
<td>+0.27</td>
</tr>
<tr>
<td>1982</td>
<td>w.-wheat</td>
<td>-0.21</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1983</td>
<td>w.-barley</td>
<td>+0.19</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1984</td>
<td>sugar beets</td>
<td></td>
<td></td>
<td>-1.01</td>
</tr>
<tr>
<td>1985</td>
<td>w.-wheat</td>
<td>+0.45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1986</td>
<td>s.-barley</td>
<td>-0.23</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1987</td>
<td>s.-oats</td>
<td>-0.39</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ø</td>
<td></td>
<td>+0.04</td>
<td>-0.38</td>
<td>-0.91</td>
</tr>
</tbody>
</table>

Another reason of the interaction might be the composition of organic matter and the wider C:N ratio of straw of cereals in comparison with straw from maize or leaves of sugar beets. The amount of N mineralised in the soil may explain the different mineralisation behaviour (table 2).
Table 2: Nitrogen mineralised (kg/ha N) in soil profile (0 - 90 cm) after different soil tillage and increasing N-fertiliser-amounts

<table>
<thead>
<tr>
<th>Crops</th>
<th>Soil tillage</th>
<th>conventional tillage</th>
<th>reduced tillage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N₀</td>
<td>N₁</td>
<td>N₂</td>
</tr>
<tr>
<td>winter cereals</td>
<td>42</td>
<td>49</td>
<td>55</td>
</tr>
<tr>
<td>spring cereals</td>
<td>43</td>
<td>51</td>
<td>46</td>
</tr>
<tr>
<td>sugar beets</td>
<td>70</td>
<td>70</td>
<td>65</td>
</tr>
<tr>
<td>maize</td>
<td>65</td>
<td>65</td>
<td>75</td>
</tr>
</tbody>
</table>

On conventionally tilled plots we could recover an influence of fertilisation. With increasing N-rate the soil nitrate increased from 42 kg/ha N to 55 kg/ha N in winter cereals. A similar relation was found in spring cereals, but after reduced tillage an influence of N-fertilisation was observed only to winter cereals. This indicates a different mineralisation behaviour in shallow tilled soils, which was measured in the soil (table 3). The C- and N-content in the soil depth of 0,15 and 15 - 30 cm was hardly influenced by N-fertilisation on plowed plots, although N-balance over the trial period showed a large difference from minus 60 kg/ha per year to plus 44 kg/ha. After the reduced tillage C-content in the layer 0 - 15 cm has been increased by fertilisation and by tillage. The higher amount of organic material at the highest N-rate which was incorporated in the soil depth of 15 cm, led to higher C- and N-contents in the upper layer.

Table 3: Influence of soil tillage on soil properties in the upper layer of soil and N-balance at increasing N-fertilisation

<table>
<thead>
<tr>
<th>soil properties</th>
<th>soil depth</th>
<th>plow tillage</th>
<th>reduced tillage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N₀</td>
<td>N₁</td>
<td>N₂</td>
</tr>
<tr>
<td>C-content (%)</td>
<td>0-15</td>
<td>1.10</td>
<td>1.05</td>
</tr>
<tr>
<td></td>
<td>15-30</td>
<td>0.98</td>
<td>0.98</td>
</tr>
<tr>
<td>N-content (%)</td>
<td>0-15</td>
<td>0.12</td>
<td>0.12</td>
</tr>
<tr>
<td></td>
<td>15-30</td>
<td>0.11</td>
<td>0.10</td>
</tr>
<tr>
<td>N-balance*</td>
<td>-60</td>
<td>-10</td>
<td>+11</td>
</tr>
<tr>
<td>(N-fertilised - N-uptake)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
* average over the period 1977 to 1987

CONCLUSION
Nitrogen fertiliser is one of the most important factors, contributing to productivity. There is a close interaction to the mineralisation which is strongly influenced by tillage management. A change from deep plowing to a more shallow tillage as done with a cultvator needs some years until a balance has been reached. A
lower tilling depth leads to a closer ratio of organic material from previous crops and soil loosened by cultivator. Due to the wide C:N-ratio of cereal, straw N-fixing processes in soil could be observed, which can be improved by N-fertilisation. Winter cereals following sugar beets or maize, could overcome the N-fixing process better than spring cereals following winter wheat or other cereals.

A balance of mineralisation appeared to be reached for winter cereals, but not for spring cereals, for which a higher N fertilizer amount could not compensate the lower tilling depth. On the other side the physical properties after reduced tillage - higher soil strength due to compaction in the depth of 15 - 30 cm - may cause less root growth and a negative yield response of sugar beets. If the cultivator is used instead of plowing, we recommend following:

1. It is necessary to notice the different crop response to reduced tillage. Winter cereals respond less negative than spring cereals or sugar beets which need a deep loosened soil.
2. N-fixing processes or less mineralisation after shallow tillage should be compensated by N-fertilisation in the first years after change.
3. When mineralisation has been balanced after six to ten years, nitrogen fertiliser is better utilized by plants than before.

REFERENCES

Baeumer, K., 1980: Nitrogen fertilisation to cereals for reduced tillage. Kali-Briefe (Büntehof) 15 (2), 77-90


THE WIDELY PRACTICED NEW RATIONAL TILLAGE FOR WHEAT

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ABSTRACT

In the period 1982 to 1987 the Institute has established a network of productive experimental fields which were cultivated by a reduced method and thus prepared for wheat. There were 125 experiments in total. The results of these experiments were very favourable for the cultivation without plow application. The harvest achieved by this reduced cultivation was 57.78 dt/ha, which is 80 kg/ha more in comparison to the standard method of cultivation. In the period of five years, the reduced method of several repetitions of discing was greatly improved, since the faults which were registered, have been eliminated.

These investigations have resulted in a new type of soil tillage which was titled: RATIONAL TILLAGE. It was adapted to our conditions and was performed by chisels. The pre-condition for high quality rational tillage is PROTECT TILLAGE which is done simultaneously with previous crop harvesting. This new way soil tillage is practiced in Vojvodina on more than 50% of the area in Vojvodina (which is ca 100 000 ha).

INTRODUCTION

The first experiments with reduced tillage in Vojvodina were carried out in 1966 (Drezgjić, Kosovac) and on to 1972 (Molnar, Konstantinović, Žugić, Dakić) and the results were most favourable for this method of tillage.

The energy crises encouraged the spreading of the reduced tillage method, as well as the maintained high level of fuel oil prices in Yugoslavia and the severe economic conditions which led to the struggle for production costs reduction.

The decisive factors in spreading of the reduced tillage method in soil preparation for wheat were the results achieved in experiments which were carried out in nearly all the estates throughout Vojvodina, which results were the same as those achieved with conventional method, as well as the experience and self-confidence of these who worked by the method.

At the beginning of this method application, numerous mistakes were made and were corrected "in the procedure" so that the contemporary method of reduced tillage is largely enhanced. It has become more intensified, the tillage profile has become more profound and of higher quality. At the moment this method is more expensive than it was at the beginning, but is more competitive to the conventional tillage.

METHOD

Vojvodina is located at the North of Yugoslavia and is the most suitable region for agricultural production. Chernozem is the most widely spread soil type and the similar ones, but the climate is semi-arid with an almost regular shortage of rainfall in the fall (September to October) when soil is being prepared for the wheat actually sown.
These productive trials were done by the Zade method - narrow plots in 4 replications. The tested tillage variations were: Conventional plowing to the depth of 25-30 cm, the control type, and Reduced tillage by discing.

The tests were carried out in all of the agro-ecological regions of Vojvodina in order to cover all types of soils and all types of climatic conditions. In 5 years 125 experiments were done.

Yields were noted in all trials, while other research was done only at the closest locations.

Except for the yield, closely observed were the soil moisture content, volume weight, porosity, and the soil density was measured by penetrometer or penetrograph.

RESULTS AND DISCUSSION

YIELD ANALYSES: The achieved results in all of the trials are shown in Table I. In the first year (1982) the conditions for soil tillage and wheat sowing were very favourable, but the early winter that year inhibited the normal development of wheat, so that wheat entered the winter poorly prepared. Winter frosts (-15°C) have partially damaged the wheat, and further on its recover was slowed down because of the dry and cold spring. May drought lasted till June 12th, so this year may be considered unfavourable for wheat. In spite of all this, the yield was 53.74 dt/ha on the fields that were treated by reduced tillage which was 0.48 dt/ha more than on the fields treated by conventional tillage. 13 out of 22 trials have given better results with Reduced tillage.

Table 1. The yields obtained by reduced tillage in 1982-1986

<table>
<thead>
<tr>
<th>YEAR</th>
<th>Conventional tillage</th>
<th>Reduced tillage</th>
<th>Difference in favour of reduced tillage</th>
<th>Number of trials</th>
<th>Ratio of conventional to reduced tillage in dt/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>1982</td>
<td>53.26</td>
<td>53.74</td>
<td>+ 0.48</td>
<td>22</td>
<td>9:13</td>
</tr>
<tr>
<td>1983</td>
<td>52.00</td>
<td>53.00</td>
<td>+ 1.40</td>
<td>26</td>
<td>9:17</td>
</tr>
<tr>
<td>1984</td>
<td>62.07</td>
<td>62.15</td>
<td>+ 0.08</td>
<td>25</td>
<td>12:13</td>
</tr>
<tr>
<td>1985</td>
<td>59.08</td>
<td>60.81</td>
<td>+ 1.73</td>
<td>27</td>
<td>13:12</td>
</tr>
<tr>
<td>1986</td>
<td>58.47</td>
<td>58.78</td>
<td>+ 0.31</td>
<td>25</td>
<td>9:16</td>
</tr>
<tr>
<td>x</td>
<td>56.98</td>
<td>57.78</td>
<td>+ 0.80</td>
<td>125</td>
<td>46:79</td>
</tr>
</tbody>
</table>

x) The ratio between the conventional and reduced tillage in number of trials with higher yield.

In the second year (1982/83) the fall was favourable for tillage, sowing and germination, and the winter was mild and without wheat freezing. However, the spring was unpleasant and only with scarce rainfall but that was moderate. In the unfavourable year the reduced tillage gave a yield of 53.40 dt/ha or 1.40 dt/ha more than conventional tillage. 17 out of 26 experiments gave better results with reduced tillage.

In the third year 1983/84 the climatic conditions were favourable for development of wheat, thus the yields on average were higher by about 10 dt/ha in relation to the 1st and 2nd years.
In that third year the yields were almost even i.e. 62.15 dt/ha in reduced and 62.07 dt/ha. This year was the only one in which the yields were higher on fields which were prepared by Conventional tillage, i.e. in 13 experiments Conventional tillage was applied and in 12 with Reduced tillage.

The fourth year was also very favourable, and the yield was 60.81 dt/ha which was more than the yields achieved by conventional tillage by 1.73 dt/ha and this was the largest achieved difference in favour of reduced tillage in the "5 years" period. By the number of experiments this year was also the one which set the record: out of 27 experiments, 20 had given better results with Reduced Tillage.

In the fifth year (1985/1986) the fall was dry, the winter was moderate, the spring was not favourable for wheat. In this last year the results were better with Reduced tillage.

SOIL PHYSICAL PROPERTIES ANALYSIS: Here will be presented only the results of research relative to the soil density measured by penetrograph (Figure 1).

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Fig.1. Soil compaction
Measured by penetrograph (in daN/cm²)
Comparing the measured soil resistance values in fall and in spring, it may be realized that soil density was higher in fall and for conventional tillage it was 17.4, while in spring it was 15.2 da N/cm² or 86%. With reduced tillage method results obtained in fall were 17.1 and spring 13.5 da N/cm² or 79%. These results may easily be explained by higher moisture content (saturated) and the recovery of the soil structure which significantly affects the soil resistance decrease. However, these are the average values and refer to the layer 50 cm thick, both cultivated and non-cultivated.

If we analyse the soil density values only for the cultivated layer then it may be observed that the conventional tillage (up to 25 cm) soil density value is 9.5 in autumn and 9.26 da N/cm² in spring, or 96% which are approximately equal values. However, with reduced tillage method the situation is reversed, so in fall for the layer up to 15 cm the average value is only 3.8 and in spring it is 4.8 da N/cm², or 126% in comparison to the measured soil density in fall. This means that the reduced tillage produces poorer density of the cultivated layer compared to the situation in spring. This may be explained by the fact that the Reduced tillage will produce a layer which is thoroughly shaken up, since repeated discing in dry conditions will produce a layer of soil which may be too fine. This is referred to as "milling". Till the next spring this fine layer of soil gets pressed due to the rain and snow, as well as by the elapse of time (gravity) and therefore the density of this layer is higher, but yet the optimum for the development of wheat.

The obtained results in our research mostly match the results of locally conducted research work (Drezgic, Kovac, Dakić) as well as those done throughout the world (Cannell, Dabney, Zumbach, Koeller, Rydberg). Our research show mostly equally results both for the reduced and conventional tillage. Why? "Our" reduced systems of tillage are more intensified. The tillage profile with reduced tillage is somewhat deeper (15-17 cm) more complete and qualitative since it is performed by discing in several replications without limits. However, the success of "Our" Reduced tillage should be looked for in objective shortcomings of the system, and also in the mistakes which are done in the process of Conventional tillage application. On soils of heavy mechanical composition in dry conditions Conventional tillage has the following shortcomings: when plowing big lumps are cut off, the furrows are opened and the losses of moisture are considerable, and the seedbed preparation consists of more stages (5-6 passes) and expensive. By use of the reduced tillage these problems are eliminated or are less remarkable.

The success of reduced tillage is largely contributed by the fact that it is used only 1 year after sugar beet, or other row crop for which the soil is deeply plowed the previous year (25-30 cm).

INNOVATIONS: In the course of the experiments we have noticed that discing, otherwise a very useful and widely used tool, is rather irregular in its operating, and have named this phenomenon "TAIL-MASCING" (picture 1).

![Picture 1. profiles of the soil cultivated by reduced tillage](image-url)
with constant change of direction (crosswise, diagonally). In harder conditions, 4-6 discings should be carried out. During this experimental work we have come up with the new system titled: The RATIONAL TILLAGE. This method is done by chisels at the depth which is equal to the Conventional tillage depth (picture 2 - right).

![Pic. 2. profiles of the soil after the Conventional and rational tillage.](image)

The quality of this tillage is much better in comparison to the reduced tillage done by discing, and in comparison to the conventional tillage, too. It is carried out more simply, faster, and much more cheaply in comparison to the Conventional tillage.

In extremely difficult conditions (soil moisture about 10% and less) the reduced tillage is done by shallow cultivation performed by sub-soiler up to 15 cm, so that soil which is "cut off" is done by discing later (2-3) times the suitable profile to the depth of 15 cm is formed. In conditions like these, only the discing, without subsoiler cultivation deeper than 4-5 cm would not be possible, which is insufficient.

PROTECT TILLAGE: This cultivation is the precondition for the new methods of tillage. Protect tillage is in our conditions a shallow tillage performed simultaneously with crop harvest such as; sugar beet, sunflower, soybeans, etc. If the preceding crop is wheat, before the Reduced tillage is done. The main goal of this operation is to protect the soil from water losses through evaporation, because after removing these crops the soil remains bare and directly exposed to the sun and wind. This type of cultivation is done mostly by discing to the depth of 5-6 cm, which is enough to interrupt formation of the soil capillarity.

Thus cultivated soil is protected from further losses of water, and the stored humidity largely affects the quality of tillage, as well as the reduction of soil resistance at cultivation which spares the fuel and the machines.

CONCLUSIONS

1. The reduced soil tillage is for wheat and is largely spread throughout Vojvodina and contributes significantly to the improvement of this production, since it maintains a high level of production and reduces the production costs considerably.

2. The research is being continued in order to improve the quality of this cultivation, since the method itself is no guarantee of success.

3. In our further work we will try to spread Reduced tillage, introduce the rational tillage done by chisels, which offers higher quality, and is not significantly more expensive than the Reduced, but a lot faster and cheaper compared to the Conventional one.

4. The success of these new methods in soil cultivation depends largely on the tools' quality, as well as on the quality of sowing machines and sowing.
LITERATURE


PEDOTECHNIQUE - INVENTORY OF PREDICTIVE METHODS, AND UNLOCKING OF RELEVANT INPUT DATA

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ABSTRACT

The scope of pedotechnique, a new interdisciplinary branch of soil science, embodied in the ISSS Working Group PT (Pedotechnique), is described. Based on knowledge of soil mechanical characteristics, pedotechnique aims at predicting the course, effects and costs of soil processes, as they occur in soil handling and field traffic. Pedotechnique uses mainly empirical and composite predictive methods. Approximation and exact predictive methods are little used. A short introduction to the development of such methods is presented. The unlocking of relevant input data is still difficult. Modification of existing soil classification systems or even entirely new classification systems will be required.

INTRODUCTION

Predictive methods are practical methods to acquire useful information (e.g. vehicle performance) from easily obtainable data (e.g. cone index). Such methods are useful in soil tillage, land locomotion, and in winning and use of raw material from the earth's crust, as they allow prediction of the course, results, and/or costs of such activities. In these fields of application, the method-users, the method-designers, and the suppliers of the necessary input data often work in different sciences. Here, the ISSS Working Group Pedotechnique, which concentrates on mechanical/physical processes, aims at performing a bridge function (Van Ouwerkerk and Koolen, 1988). When shifting from relatively extensive soil use, as in traditional agriculture, to very intensive soil use, as in cut-flower production in glasshouses and in the ceramic industry, the chances of successful introduction of predictive methods increase. Here, the decisive factor is the mechanical/physical complexity in relation to the value of the particular use. Therefore, aspects of economics and quality considerations play an important role.

Scientifically, it would be most satisfactory if the really important soil qualities could be predicted as, for plant growth, soil water, gas and heat capacities and conductivities and root penetration resistance, and, for field traffic, flotation and traction. However, often this cannot be achieved, and then attention is focussed on soil qualities "at a lower level", such as bulk density, and composition of soils or mixtures of soils. From a scientific point of view this reduces the number of potential solutions unnecessarily. The data that are relevant in a given application can be specific for different stages of the
Fig. 1. Prediction of the effects of a mechanical/physical process on soil qualities may use soil mechanical/physical properties, soil micro-factors prevailing at time \( t \), soil characterization processes such as cone measurement, and/or sequence of previous natural and man-induced processes.

manufacturing process. For example, the ceramic industry makes different demands on the raw soil material, the ceramic body, the newly shaped product and the finished product.

Although specifications often do not have a sound scientific basis, they are required to make possible the conclusion of contracts between customer and contractor. The required accuracy of prediction varies. It does not necessarily have to be great, for instance in the field of environmental protection, or if safety is put first and safety factors are introduced as in civil engineering. Individual companies demand low-cost predictive methods with high accuracies so as to minimize prediction costs and costs due to wrong predictions.

The usefulness of the large body of easily available data on soils is far from perfect. To improve the usefulness of these data is an important goal of the Working Group Pedotechnique.

PREDICTIVE METHODS

Prediction by means of analytical solutions would be ideal, but this procedure hardly occurs in soil tillage, land locomotion, and winning and use of raw soil materials. The introduction of the computer removed many arithmetic limitations, but it also revealed other limitations, in particular the inability of properly measuring soil stress-strain relations and yield criteria. This inability is due to the fact that in pedotechnical problems strains are large, three-dimensional, and strongly rate-dependent. It has led to the use of indirect determinations, a famous example being the calculation of soil cohesion and angle of internal friction from simple shear and penetration measurements at the moon's surface (Costes et al., 1972). Therefore, non-analytical solutions prevail, examples of which are given in a following section.

Any predictive method needs information, i.e. characteristics, from which process aspects can be derived. The following characteristics are relevant (Fig. 1).

Relationships observed between "treatments" and "behaviour". In a process, soil mechanical behaviour will depend on the different treatments to which the soil has been subjected prior to the process in question.
Fig. 2. Classic tests to characterize soil. a) Cone penetrometer test. b) Proctor test. c) Pfefferkorn test.

Knowledge of the relationships between soil treatment and behaviour provides a basis for the prediction of process aspects when the previous treatment is known. Such relationships are used to predict behaviour of materials in depots, tempering silos etc., and may be a solution for problems of soil-tool adhesion and slaking after seedbed preparation.

Soil micro-factors. These factors comprise the nature, amount, and distribution of solid particles and water in a unit volume of soil, and the noncapillary bonds between soil particles (strength-determining factors). They determine soil behaviour according to physical laws, but may also be used for identification purposes.

Soil macro-factors, which concern soil mechanical and physical properties that are relevant where soil is considered as a continuum, for example the compressibility of the bulk soil.

Characterization processes. These processes involve strongly non-homogeneous states of stress and strain. However, because of their simplicity, methods which measure the complex resultant pressure or deformation are still widely used. Important examples are the cone penetration test in agriculture, the Proctor test in civil engineering, and the Pfefferkorn test in the ceramic industry, which determines the decrease in height of an unconfined column of remoulded wet clay due to a falling-weight treatment (Fig. 2).

EXAMPLES OF PREDICTIVE METHODS

Predictive methods may be divided into two main groups (Koolen and Kuipers, 1983). The first main group comprises methods based chiefly on observation of relationships between soil characteristics and process aspects (black-box methods). It is subdivided into a) comparative methods, and b) methods using empirical formulae or graphs. The second main group comprises methods based mainly on knowledge of the mechanism of the process under consideration. It is subdivided into a) approximation methods, and b) exact methods. Meanwhile, it has become clear that a third main group should be distinguished, called composite methods, which contain a number of elements from the first two main groups.
Composite methods usually yield a large amount of information, but their accuracy is often questionable.

Comparative methods

Although scientifically not fully satisfactory, this group is of great practical importance, as is shown in the following examples. The use of series of standards, defined by characteristics. The motor-car factory of Volvo has listed a series of terrain conditions, characterized by photographs and cone index values, along with corresponding maximum dumper capacities (Anonymous, 1981). The dumper capacity in a particular terrain can be estimated by ranking this terrain according to a scale of standards. In an investigation to determine detectability of soil slaking from radar back-scatter, Koolen et al. (1979) determined the degree of soil slaking by using a standard series of photographs from Boekel (1976). In the laboratory, using a standard series involving different soil types, porosities, and moisture contents, the degree of soil crumbling following rotary cultivation could be predicted on the basis of penetration resistance, shear resistance, unconfined compressive strength, and failure strain in unconfined compression testing (Koolen and Kuijpers, 1983).

Inquiry is a powerful method. Perdok and Hendrikse (1982) and also Van Wijk and Buitendijk (1986) assessed workability limits by means of objective workability tests, starting from workability estimates made by a large number of farmers. Van Wijk (1980) established a relationship between cone index and playability of sports turfs, starting from playability estimations by groundsmen. In the Netherlands, the "Technical regulations for soil mixtures for city trees, public parks and gardens", to be used in contracts between customers and contractors, have been evaluated through questionnaires filled in by experts in these fields. Similarly, the sensitivity of military training grounds to dust formation has been determined in relation to soil texture. Löffler (1982) successfully interviewed forest managers to establish a very useful terrain classification for forestry operations.

Test objects, such as experimental fields in plant production and operated by Agricultural Advisory Services. The predictive value of test objects is high if the pertinent characteristics (the domain) vary little, as is the case with hockey fields, lawn tennis courts, etc.

Methods involving empirical formulae or graphs

Several research workers formulated mobility numbers to predict tyre performance from cone penetrometer measurements (Wismer and Luth, 1973). Perdok and Van de Werken (1983) presented empirical formulae to predict power requirements of rigid-tine cultivators, rotary harrows, spiked rotary tillers and blade-type rotary tillers. They used only one soil characteristic, i.e., the specific ploughing resistance. Prediction was feasible by confining the domain of the problem to typical values of soil density, working depth, tool width, forward speed, and/or shaft angular velocity. Under laboratory conditions, tyre rut depth and accompanying soil compaction could be predicted very accurately by using not one, but two characterization processes: the cone index and the depth of the hole made by a falling weight (Tijink and Koolen, 1985).

Approximation and exact methods
Approximation methods, such as the determination of the rolling resistance according to Bekker's theory, and exact methods, such as the finite-element method, are little used.

Composite methods

Several soil classification systems present process aspects that can be directly applied. For Romania, Canarache (1987) described land classification systems with respect to: the need for deep ripping, suitability for minimum tillage, specific needs in soil tillage, suitability for mechanized potato harvesting, specific ploughing resistance, and soil compaction sensitivity of the arable layer. In Finland, during 1967-1970, a new system for classifying the "diggability" of soils was developed by Arhippainen and others (Korhonen and Gardemeister, 1972). Schmidt and Rohde (1986) presented soil moisture limits for the use of 16-20 tyres on grassland on imperfectly drained peatland. For a number of soil types Petelkau (1986) assessed upper soil bulk density limits for satisfactory crop production. Expectations for computer simulation models run very high, but there is a growing need for experimental verification of such models. Basically, scale model testing is a comparative method. However, because of corrections, necessary due to experimental problems, it should be classified as a composite method. An example was given by Reece (1983).

UNLOCKING OF RELEVANT INPUT DATA

To increase the usefulness of information required for prediction, a number of activities are desired.

Methods to determine soil characteristics should be further standardized so as to facilitate connection with work already done. Knowledge of relations between soil characteristics is very useful as it permits derivation of desired, unknown characteristics from other, known characteristics. In the literature, several such relations are listed (Renger, 1971; Koolen and Vaandrager, 1984; Jones et al., 1986). This knowledge also allows selection of characteristics that are mutually independent, so that prediction accuracy can be increased (Tijink and Koolen, 1985).

Existing soil classification systems from which input data can be derived may be modified to improve their usefulness in pedotechnique. For example, Larson et al. (1980) presented compressibility diagrams for agricultural soils from eight soil orders. In our opinion it may, for specific applications, even be useful to introduce entirely new classification systems.

LITERATURE


RESIDUE MANAGEMENT, NITROGEN, AND TILLAGE EFFECTS ON GRAIN
YIELD OF PADDY RICE FOR A SANDY HYDROMORPHIC SOIL IN WESTERN
NIGERIA

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SUMMARY

Effects of 2 levels of N on grain yields of paddy rice for 7 consecutive crops
were investigated for no-till and puddling methods of seedbed preparation for a
sandy, kaolinitic, isohyperthermic Aeric Tropaqualf in western Nigeria. Two rice
crops were grown every year. Rice stover was removed in puddled plots and left on
the surface in no-till treatments. For the first 4 crops, there were no effects of
tillage methods on rice grain yield. Yield was however, significantly affected by
nitrogen application. The grain yields of the 5th and 6th crops were significantly
lower, by 24 to 35%, respectively, in the no-till than puddling system of seedbed
preparation. For the subsequent crop, when rice straw was removed from the
no-till treatment prior to transplanting, equivalent rice yields were obtained for
both tillage treatments. Rice grain yield declined with the duration of cultivation
from 6.3 Mg/ha in 1978 to 4.1 Mg/ha in 1981 with N application, and from 5 Mg/ha
in 1978 to 3.3 Mg/ha in 1981 without application of nitrogenous fertilizer. Grain
yield was always more for the first than the second season crops.

INTRODUCTION

Puddling, a wet tillage system to destroy soil aggregation and reduce water
percolation rate, is a common method of seedbed preparation for transplanted rice.
Effects of soil puddling on rice grain yield depend on antecedent soil structure and
infiltration rate, internal drainage and the degree of anaerobiosis, and the landuse
history (Curfs, 1976; Lal, 1984; Rodriguez and Lal, 1985; Ogunremi et al, 1986; Lal,
1986). Inherent soil fertility, rate of fertilizer application, weed incidence and
control measures also play an important role in determining yield effects of
puddling.

Effects of wet or dry tillage on soil physical properties depend on particle size
distribution, predominant clay minerals, and tillage intensity (Sanchez, 1973a; b;
De Datta et al, 1979, De Datta and Karim, 1974; Lal, 1984; IRRI, 1984). In
general, tillage effects are less drastic in coarse-textured soils containing
low-activity clays than in heavy-textured soils with high-activity clays. The
magnitude of effects also depend on the period for which a soil has been subjected
to puddling operation, and the type of tillage performed for growing an upland crop
grown in the post-rainy season.

Considerable research information exists regarding the effects of tillage
methods on rice yield and properties of soils in Asia. There is a paucity of such
information, however, for coarse textured, hydromorphic soils in West Africa. The
objective of this experiment, therefore, was to evaluate the effects of puddling and
no-till system of seedbed preparation on rice grain yield for a coarse-textured,
yhedromorphic soil recently developed for rice cultivation.
METHODS AND MATERIALS

Field experiments were conducted for 7 consecutive seasons from 1978 through 1981, at the experimental farm of the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria. IITA is located approximately 30 km south of the northern limit of the lowland rainforest. The average annual rainfall of about 1200 mm is received over two distinct seasons. The first major season lasts from late March to late July, and the second shorter season begins in late August and ends in early November. The experiment was conducted on a hydromorphic valley-bottom soil. The soil is coarse textured, sandy, kaolinitic, isohyperthermic, Aeric Tropaquent. The surface soil contains 69% sand, 16% clay, and 15% silt. This soil has been under rice cultivation since 1973.

There were two tillage methods—no-till (T0) and puddling (T1). After dry tillage, puddled plots were plowed in standing water to about 15 cm depth. The no-till plots were sprayed with 5 l/ha of paraquat (1, 1' dimethyl 4, 4' bipyridilium ion) two days before transplanting. The rice straw from plowed plots was removed before plowing while that from the no-till plots was kept on the surface. There were two levels of N—N0 (no nitrogen) and N1 (100 kg/ha of N). The experiment was a complete factorial combination of two tillage systems and two nitrogen levels in 4 completely randomized blocks. There were 16 plots of 99 m² each (10.3 x 9.6 m).

Four-week old rice seedlings of cultivar IITA-212 were manually transplanted in 2-5 cm deep standing water. Tiller count, plant height and grain and stover yield were measured at maturity.

RESULTS

Rice Yield:

Effects of tillage methods and nitrogen application on number of tillers per 16 hills (Table Ia, b) plant height at different days after transplanting (Table Ila, b) and grain yield (Table III) for the 1980-season crops are shown in Tables I to III. Grain yields for the 2 initial crops were reported earlier by Rodriguez and Lal (1985). For the first and the second season crops in 1979, there was no effect of tillage methods on rice grain yield. The mean grain yield was about 5.7 and 3.0 Mg/ha for both tillage methods for the first and second season crops, respectively (results not reported). There was, however, a significant response to N application for both tillage methods. In the first season of 1979, there was about 50% increase in rice yield due to N application in no-till and about 38% increase in the puddling method of seedbed preparation. In the second season of 1979, rice grain yields were lower but the trends in relation to fertilizer application were identical. Plant height and the tillers also followed a trend similar to that of the grain yield.

Rice grain yields for the 1980 crops were significantly lower in no-till than in conventionally puddled plots for both levels of N application (Table III). There was no response to N application either for no-till or the puddling methods for the first season crop. The mean grain yield for the no-till system was about 35% lower than that of the puddled treatments in the first season and 24% lower in the second. Seedling establishment in no-till plots was poor compared with the puddled treatments. Seedlings in no-till plots were slow to start, had lesser plant height, and lower tiller count at all growth stages than in puddled plots (Tables I and II). The height at maximum tillering was short. The mean tiller count at
Table Ia. Effects of tillage methods and nitrogen on tiller production (number/16 hills). First season 1980.

<table>
<thead>
<tr>
<th>Nitrogen</th>
<th>Tillage</th>
<th>Days after transplanting</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>15</td>
</tr>
<tr>
<td>N₀</td>
<td>T₀</td>
<td>68a</td>
</tr>
<tr>
<td>N₁</td>
<td>T₀</td>
<td>61ab</td>
</tr>
<tr>
<td>N₀</td>
<td>T₁</td>
<td>59ab</td>
</tr>
<tr>
<td>N₁</td>
<td>T₁</td>
<td>56b</td>
</tr>
</tbody>
</table>

T₀ = No-till, N₀ = No nitrogen, T₁ = Puddling, N₁ = 100 kg/ha N.

Table Ib. Effects of tillage methods and nitrogen application on tiller production (number/16 hills). Second season 1980.

<table>
<thead>
<tr>
<th>Nitrogen</th>
<th>Tillage</th>
<th>Days after transplanting</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>20</td>
</tr>
<tr>
<td>N₀</td>
<td>T₁</td>
<td>39b</td>
</tr>
<tr>
<td>N₁</td>
<td>T₁</td>
<td>77a</td>
</tr>
<tr>
<td>N₁</td>
<td>T₀</td>
<td>70a</td>
</tr>
<tr>
<td>N₀</td>
<td>T₀</td>
<td>34b</td>
</tr>
</tbody>
</table>

Table Ila. Effect of tillage methods and nitrogen application on plant height (cm). First season 1980.

<table>
<thead>
<tr>
<th>Nitrogen</th>
<th>Tillage</th>
<th>Days after transplanting</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>15</td>
</tr>
<tr>
<td>N₀</td>
<td>T₁</td>
<td>43.2a</td>
</tr>
<tr>
<td>N₁</td>
<td>T₀</td>
<td>42.3a</td>
</tr>
<tr>
<td>N₁</td>
<td>T₁</td>
<td>41.2a</td>
</tr>
<tr>
<td>N₀</td>
<td>T₀</td>
<td>40.9a</td>
</tr>
</tbody>
</table>

Table Iib. Effects of tillage methods and nitrogen on plant height (cm). Second season 1980.

<table>
<thead>
<tr>
<th>Nitrogen</th>
<th>Tillage</th>
<th>Days after transplanting</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>20</td>
</tr>
<tr>
<td>N₀</td>
<td>T₁</td>
<td>46.3b</td>
</tr>
<tr>
<td>N₁</td>
<td>T₁</td>
<td>50.0ab</td>
</tr>
<tr>
<td>N₁</td>
<td>T₀</td>
<td>52.8a</td>
</tr>
<tr>
<td>N₀</td>
<td>T₀</td>
<td>43.0c</td>
</tr>
</tbody>
</table>
maximum tillering in no-till plots was about 24% lower in the first season and 19% lower in the second season than in puddled plots (Table Ia and b).

The grain yield of the second season, 1980, crop was lower than that of the first season, by as much as 80% (data not reported). The mean grain yield of the no-till treatment was about 24 percent lower than the puddled plots. Contrary to the first season, however, there was a positive response to N application for both methods of seedbed preparation. The mean response to N was 55% in no-till and 52% in puddling treatments. Similar trends were observed in plant height and the maximum tiller count.

Rice straw was removed from both no-till and the plowed plots prior to spraying paraquat or plowing for the 1981 crops. Consequently, seedling establishment for this crop was satisfactory and identical in both tillage treatments. Crop growth and grain yields were also similar (Table IV). The mean grain yield was 3.8 Mg/ha in the no-till treatments and 3.7 Mg/ha in the puddled treatments. There was no response to N in either of the tillage methods. Application of N fertilizer, however, produced a positive response in tiller production: 25 percent increase in no-till and 21 percent in the puddling system.

Table III. Effects of tillage treatments and nitrogen level on rice grain yield in 1980.

<table>
<thead>
<tr>
<th>Nitrogen</th>
<th>Tillage</th>
<th>First season (t/ha)</th>
<th>Second season (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N₀</td>
<td>T₀</td>
<td>5.9a</td>
<td>2.0b</td>
</tr>
<tr>
<td>N₁</td>
<td>T₀</td>
<td>5.3ab</td>
<td>3.1ab</td>
</tr>
<tr>
<td>N₂</td>
<td>T₁</td>
<td>4.3b</td>
<td>3.0b</td>
</tr>
<tr>
<td>N₀</td>
<td>T₀</td>
<td>4.0b</td>
<td>2.0c</td>
</tr>
</tbody>
</table>

Table IV. Effects of residue removal in no-till plots on rice grain yield in 1981.

<table>
<thead>
<tr>
<th>Nitrogen</th>
<th>Tillage</th>
<th>Maximum plant height (cm)</th>
<th>Maximum tiller No./16 hills</th>
<th>Grain yield (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N₀</td>
<td>T₀</td>
<td>103a</td>
<td>109a</td>
<td>3.4a</td>
</tr>
<tr>
<td>N₀</td>
<td>T₁</td>
<td>106a</td>
<td>120a</td>
<td>3.6a</td>
</tr>
<tr>
<td>N₁</td>
<td>T₀</td>
<td>110a</td>
<td>136bc</td>
<td>4.1a</td>
</tr>
<tr>
<td>N₁</td>
<td>T₁</td>
<td>112a</td>
<td>145c</td>
<td>3.7a</td>
</tr>
<tr>
<td>LSD(.05)</td>
<td></td>
<td>11</td>
<td>21</td>
<td>0.8</td>
</tr>
</tbody>
</table>

Long term Trends: There were no significant differences in rice grain yield due to the methods of seedbed preparation for the first 4 consecutive crops. The grain yields of the first season crops (1, 3, 5 and 7) were generally higher than the second season crops. In 1980, rice grain yields for the no-till system were significantly lower than for the puddling treatments. With the removal of crop
residue for the 1981 crop, however, equal yields were once again obtained with both methods of seedbed preparation. Rice grain yield progressively declined, from an initial yield of about 6.3 Mg/ha in 1978 to about 4.1 Mg/ha in 1981 with N application, and from about 5 Mg/ha to 3.5 Mg/ha without N.

CONCLUSIONS

1. Consistently lower rice yields in the second season are probably due to low level of radiation, and buildup of insects and pathogens. The decline in rice grain yield with increasing duration of cropping may be attributed to fertility depletion of this sandy soil, and to an increase in weed incidence.

2. For this coarse-textured soil, puddling had no drastic effect on soil physical properties. These results will be reported in a separate report.

3. Decline in rice yield in no-till plots when residue was left on the soil surface was due to poor crop stand, stunted seedling growth, and less tillering. These adverse effects may be due to anaerobic decomposition of rice straw (Moraes, 1973; Tokunaga et al, 1971, 1972).

4. When rice straw was removed and nitrogen was applied at 100 kg/ha, there were no differences in rice grain yield in no-till and puddling methods of seedbed preparation.

REFERENCES


EFFECTS OF EIGHT METHODS OF PREPARING SEEDBED ON INFILTRATION RATE AND CORN GRAIN YIELD FOR A TROPICAL ALFISOL

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SUMMARY

Effects of eight tillage methods on corn grain yield and soil physical properties were investigated for a tropical Alfisol in Western Nigeria for 16 consecutive crops from 1980 through 1987. Tillage treatments included no-till (A) without and with chiselling (B), plowing followed by (fb) 2 harrowings (C), disc plowing (fb) rotovation (D), no-till without mulch (E), plowing in the dry season and harrowing at sowing (F), plowing fb harrowing plus mulch (F), and plowing fb harrowing and contour ridges.

There were significant differences in corn grain yield due to tillage, seasons, and the cultivation duration. Mean corn grain yield (average of 8 years) was 3.59 and 1.45 t/ha for the first and second seasons, respectively. The average yield of 16 crops for 8 treatments was 2.73, 2.62, 2.59, 2.48, 2.45, 2.41 and 2.31 t/ha for treatments A, C, D, G, B, E, F, and H, respectively. The mean grain yield declined from 4.2 t/ha/yr in 1980 to 1.1 t/ha/yr in 1987.

Tillage methods had significant effects on infiltration rate. The highest infiltration rate was measured on ridge top and in no-till and mulch treatments. The lowest infiltration was recorded in furrow bottom.

INTRODUCTION

Crop response to methods of seedbed preparation depends on many interacting factors including the type of tillage implements, the degree of soil disturbance, intensity and frequency of tillage performed, crop and the cultivar, cropping systems, soil and crop management practices, landuse history, prevailing climatic conditions, pest incidence, and the antecedent soil properties. Crop response to tillage, being an integrated effect of these and many other local-specific factors, is difficult to generalize. That is precisely the reason of contradictory results obtained for the same soil but for different crops or cropping systems; different seasons or rainfall distribution patterns; and for the same crop but for different antecedent soil properties and climatic environments. Many recent reviews have highlighted the importance of these factors and the futile attempts at generalization of the results beyond the ecological limits of the regions in which experiments were conducted (Lal, 1986a; Sprague and Triplett, 1986; Unger, 1986; D'Itri, 1985).

Because of the complexity of factors involved, it is important that longterm field experiments be setup to establish yield trends as influenced by seasonal variations in moisture availability, and cultivation-induced alterations in soil properties. Seemingly contradictory results reported in the literature from semiarid West Africa (Charreau and Nicou, 1971; Charreau, 1977; Chapart and Nicou, 1976; Nicou 1974a; b) versus subhumid and humid regions of West Africa (Lal, 1983; Lal, 1984; Lal, 1986b) are explainable on the basis of ecological
differences in soil, cropping systems, and rainfall regimes (Charreau, 1977; Lal, 1985). Furthermore, crop response to tillage may be different in the beginning of the experiment than a few years after.

The objective of this longterm field experiment, therefore, was to evaluate the effects of a range of methods of seedbed preparation on physical properties of a tropical Alfisol and on maize grain yield. The results presented herein are those obtained after 6 years of initiating the experiment. Crop response for the initial 5 years have been reported earlier (Lal, 1986c).

METHODS AND MATERIALS

A field experiment was established in 1980 at the experimental farm of the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria. IITA is located approximately 30 km south of the northern limit of the lowland rainforest. The average annual rainfall of 1100 to 1300 mm is received over two distinct seasons due to bimodal character of rainfall distribution. The first major season lasts from late March to late July, and the shorter second season begins in late August and ends in early November. There are two dry seasons, a short one from late July to late August and a long one from early November to late March.

The soil of the experimental site belongs to Ibadan series, and is classified as clayey, skeletal, isohyperthermic, kaolinitic Oxic Paleustalf. The soil is sandy near the surface and is characterized by a gravelly horizon comprising a variable concentration of quartz gravels.

There were eight tillage treatments: A, No-till with previous-season crop residue retained as mulch. B, No-till with previous-season crop residue mulch and chiselling in the row zone to about 30 cm depth once a year in the dry season. C, Moldboard plowing followed by (fb) two harrowings. D, Disc plowing fb rotovation. E, No-till with crop residue removed. F, Moldboard plowing in the dry season, two harrowings just before seeding. G, Moldboard plowing fb two harrowings and crop residue replaced as mulch. H, Moldboard plowing fb two harrowings, and contour ridging. Ridges were made manually, 75 cm apart and about 30 cm high.

Maize was seeded twice a year about mid April during the first season and late August in the second. All no-till plots were sprayed with paraquat (1, 1' dimethyl 4, 4' bipyridilium ion) at 0.5 kg ha⁻¹ a.i. Corn was seeded manually with a jab planter at 75 cm between and 25 cm within row spacing. There were three blocks of eight plots each, and treatments within blocks were assigned at random. The individual plot size was 10 x 10 m. Corn received fertilizer at 100 kg N, 30 kg P, and 30 kg K ha⁻¹.

Infiltration rate was measured once every year during the dry season using the double-ring infiltrometer. Soil bulk density and penetrometer resistance were measured for 0–5 and 5–10 cm depths. Soil moisture retention characteristics were determined using a combination of Tension Table and Pressure Plate Extractors. Grain yield was measured at maturity.

RESULTS

Grain Yields: Corn grain yield was significantly influenced by tillage methods, seasons, and the interaction among tillage methods and seasons (Table 1).
Table 1. Effects of tillage methods on corn grain yield in 1987—eight years after imposing tillage methods.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>8-year average yield (1980-1987)</th>
<th>1987 Yield (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>First season</td>
<td>Second season</td>
</tr>
<tr>
<td>A. No-till with mulch</td>
<td>3.98</td>
<td>1.47</td>
</tr>
<tr>
<td>B. No-till with mulch, chiselling in dry season</td>
<td>3.58</td>
<td>1.39</td>
</tr>
<tr>
<td>C. Mouldboard plowing fb two harrowing</td>
<td>3.62</td>
<td>1.63</td>
</tr>
<tr>
<td>D. Disc plowing fb rotovation</td>
<td>3.56</td>
<td>1.62</td>
</tr>
<tr>
<td>E. No-till without mulch</td>
<td>3.55</td>
<td>1.36</td>
</tr>
<tr>
<td>F. Plowing in the dry season, harrowing at sowing</td>
<td>3.39</td>
<td>1.44</td>
</tr>
<tr>
<td>G. Plowing fb two harrowing, with mulch</td>
<td>3.74</td>
<td>1.35</td>
</tr>
<tr>
<td>H. Plowing fb two harrowing, and ridging</td>
<td>3.27</td>
<td>1.35</td>
</tr>
</tbody>
</table>

LSD (.05)  
(i) Treatment 0.24  
(ii) Season 0.12  
(iii) Treatment x season 0.34

Eight-year average yield for the first season was the highest for the no-till with mulch (A) fb plowing with mulch (G). There were no significant differences among treatments B, C, D and E. The least grain yield was obtained in ridged treatment (H). The 8-year average yields were drastically lower for the second than in the first season. Similar to the first season results, the ridged treatment produced the lowest grain yield in the second season also. In comparison with the 8-year average, there was a drastic yield reduction for both season crops in 1987. Mean grain yield for 1987 was merely 42.6 percent of the 8-year mean for the first season and 41.1 percent for the second season. For the first season 1987 crop, the highest grain yield was obtained for the mulch and no-till treatments. For the second season, however, the maximum grain yields was observed for treatment C, and the minimum for treatments E and H (Table 1).

Infiltration Capacity: Cumulative infiltration and infiltration rate measured during the dry season 1986 are shown in Table 2. Expectedly, the cumulative infiltration and the equilibrium infiltration rate were maximum for the ridge top and the lowest for the furrow bottom, latter being the controlling factor in determining field infiltration rate during heavy rainstorms. All furrows were full of waters for as long as 24 hours after heavy rains. In contrast, field infiltration rates were the highest for all no-till plots (A, B and E). No standing water or inundation was ever observed in any of the no-till plots even after heavy rains.

Soil Bulk Density: Soil bulk density measurements, made during the dry season each year, indicated that with time soil bulk density of the surface 0–5 cm and 5–10 cm layers increased. It was low at the beginning of the experiment (Table 3).
Table 2. Cumulative infiltration and infiltration rate as influenced by tillage methods 6 years after imposing tillage treatments (measured in January 1986).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Infiltration</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cumulative cm/2 hr</td>
<td>cm/hr</td>
</tr>
<tr>
<td>A. No-till with mulch</td>
<td>267 ± 69</td>
<td>112 ± 32</td>
</tr>
<tr>
<td>B. No-till with mulch, chiselling in dry season</td>
<td>280 ± 35</td>
<td>126 ± 24</td>
</tr>
<tr>
<td>C. Mouldboard plowing fb two harrowing</td>
<td>196 ± 101</td>
<td>80 ± 32</td>
</tr>
<tr>
<td>D. Disc plowing fb rotovation</td>
<td>214 ± 52</td>
<td>95 ± 50</td>
</tr>
<tr>
<td>E. No-till without mulch</td>
<td>218 ± 214</td>
<td>136 ± 82</td>
</tr>
<tr>
<td>F. Plowing in the dry season, harrowing at sowing</td>
<td>178 ± 81</td>
<td>42 ± 20</td>
</tr>
<tr>
<td>G. Plowing fb two harrowing, with mulch</td>
<td>146 ± 163</td>
<td>29 ± 17</td>
</tr>
<tr>
<td>H-1 Plowing fb two harrowing, and ridging</td>
<td>477 ± 327</td>
<td>229 ± 128</td>
</tr>
<tr>
<td>H-2 Furrows</td>
<td>86 ± 80</td>
<td>30 ± 23</td>
</tr>
</tbody>
</table>

The infiltration data fitted the model \[ l = at^b \] rather than \[ l = St^{1/2} + At \].

Table 3. Effects of tillage methods on soil bulk density 2-years after starting the tillage treatments.

| Treatment                                      | Bulk density (g/cm³) |       |
|                                                | 0-5 cm          | 5-10 cm|
| A. No-till with mulch                          | 1.20            | 1.40   |
| B. No-till with mulch, chiselling in dry season| 1.27            | 1.27   |
| C. Mouldboard plowing fb two harrowing         | 1.30            | 1.33   |
| D. Disc plowing fb rotovation                  | 1.13            | 1.13   |
| E. No-till without mulch                       | 1.20            | 1.17   |
| F. Plowing in the dry season, harrowing at sowing| 1.23            | 1.33   |
| G. Plowing fb two harrowing, with mulch         | 1.23            | 1.27   |
| H. Plowing fb two harrowing, and ridging        | 1.26            | 1.30   |

LSD (.05)

(i) Treatment 0.10
(ii) Depth 0.05
With time, however, soil bulk density increased in all tillage treatments. The relative increase was more in no-till plots without crop residue mulch than in no-till with mulch, and chiselled or plowed treatments. The data on penetrometer resistance was in accord with that of the soil bulk density. There were, however, no apparent trends in soil bulk density and infiltration rate. The latter was influenced more by the presence of biochannels (earthworm and root channel persistence in no-till plots) than by density of the soil matrix.

CONCLUSIONS:

1. Corn grain yield was influenced by tillage methods, seasons, and time after initiating the experiment. Yields were more in the first than in the second season, in no-till and mulched plots than in ridged and unmulched treatments, and in the beginning than in later years of the experiment.

2. Infiltration rate was influenced more by the presence of biochannels than by soil bulk density and penetrometer resistance. Field infiltration rates were highest in no-till and mulched treatments.

3. Corn grain yield declined with continuous cultivation.

REFERENCES:


ACKNOWLEDGEMENTS

Help received from Mr. Ken Scaife in conducting statistical analyses is gratefully acknowledged.
SOIL PROPERTIES OF A NORTHERN CORN BELT MOLLISOL (USA) AS AFFECTED BY TILLAGE

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Federal Research Center of Agriculture (FAL), Institute of Crop Science and Plant Breeding, Braunschweig, FRG

ABSTRACT

Bulk density, clod density, pore size distribution, penetrometer resistance, aggregate size distribution and stability, and double ring infiltration measurements were taken from three tillage systems in nonwheel-track and wheel-track interrows in a continuous corn (Zea mays L.) and corn-soybean (Glycine max L.) rotation early in the cropping season. Objectives were to quantify soil properties related to water infiltration, aeration, and soil strength at a period when these factors should have a direct effect on crop performance. A conventional fall moldboard plow, spring disk tillage resulted in the most desirable qualities. Benefits to crop rotation were observed for most physical parameters measured. Wheel traffic resulted in a deterioration of soil properties. Corn yield did not significantly react to the variation in soil properties resultant from tillage.

INTRODUCTION

Soil structural properties can be modified by tillage. In fact, a primary reason for tillage is establishment of a satisfactory seedbed. Soil properties established by tillage are not static. Wind and rain, freezing and thawing, or wetting and drying will begin to change soil properties back to pretill conditions. Other external forces such as wheel traffic during planting, spraying, or harvest will also rapidly change soil structural properties established by tillage.

Lindstrom and Onstad (1984) measured soil properties after planting on a northern Corn Belt mollisol and related these properties to water infiltration, water runoff, and soil erosion. Benoit and Lindstrom (1987) expressed caution in interpreting such data because actual conditions established by tillage are a function of soil type, moisture conditions at time of tillage, surface residue, and external forces acting on the soil with time. Voorhees and Lindstrom (1984) reported that soil characteristics related to a tillage practice may also change based on the number of years a specific practice has been in effect. For example, the soil properties resultant from the first time of moldboard plowing sod will not necessarily be the same properties measured after ten consecutive years of moldboard plowing this same field.

The measurement of soil properties does have value when the measured soil properties are related to conditions that are prevalent at that point in time. In the case of the data presented by Lindstrom and Onstad (1984), the measurements reported were directly related to soil moisture recharge and the soil's susceptibility to water erosion and were taken at
the time of normal increase in rainfall amounts and intensities. Measurements reported from this study are related to water infiltration, aeration, and soil strength during a period when crops are actively growing and these factors will have a direct relationship to crop performance.

METHODS

Three tillage systems were established in the fall of 1980 on a Barnes loam (fine-loamy, mixed, mesic, Udic Haploborolls) with 2% slope on the Swan Lake Research Farm near Morris, Minnesota. Tillage systems established were a) fall moldboard plow, spring disk; b) fall chisel plow, spring disk; and c) no-till plant. These treatments will be designated as conventional tillage (CONV), reduced tillage (RED), and no-till plant (NTP), respectively. Tillage treatments were replicated four times in a randomized complete block design. A continuous corn (*Zea mays* L.) and corn-soybean (*Glycine max* L.) rotation was initiated as split plots within a tillage variable during the 1981 cropping season.

Primary tillage was done in October after harvest; spring tillage was done one or two days prior to planting. The corn and soybeans were planted with a commercial 4-row planter at the same time on 76 cm row spacing. A fluted coulter was mounted directly ahead of the seed opener for the no-till plant treatment. Individual plots were 12 rows wide by 20 m long. All treatments were cultivated twice during the growing season. The no-till plant treatment was ridged over the row at the time of second cultivation; subsequent planting was into this ridge which remained overwinter. Ridge height at planting was approximately 10 cm. Standard herbicide and insecticide applications were made as conditions dictated. Fertilizer was applied as recommended from yearly soil test analyses. Phosphorus and potassium was applied as starter with the planter, 5 cm below and 5 cm to the side of the seed. Nitrogen was applied as urea, sidedressed at first cultivation.

Soil measurements taken were bulk density, clod density, total porosity, pore size distribution, penetrometer resistance, aggregate size distribution and stability, and double ring infiltration. Bulk density samples were collected with a double-walled cylinder; inner core size was 51 by 53 mm giving a total volume of 100 mm². Total porosity was calculated from bulk density. Pore size distribution was determined from the core samples by water extraction at 50 cm and 600 cm of tension and from oven dry weights. Penetrometer resistance was taken with a recording penetrometer with resistance being recorded by 2.5 cm increments down to 30 cm and 5 cm increments to 50 cm. Problems were encountered with the penetrometer because of small rocks and cobbles inherent to the Barnes soil type. Aggregate size distribution was determined with a rotary sieve. Size separation of aggregates was <0.5, 0.5 - 1.0, 1.0-2.0, 2.0-3.0, 3.0-5.0, 5.0-9.0, 9.0-12.0, and >12 mm. Stability was determined by the wet sieve method; samples were not premoistened before sieving. Double ring infiltration was determined with a 30 cm inner ring and a 60 cm outer ring with 5 cm head of water. The inner ring was filled first to eliminate problems with air entrapment. Four replicates of all measurements were run. All measurements were taken in non-wheel-tracked interrows (NWT) and in wheel-tracked (WT) interrows. Wheel-track refers to the tractor tire track from the planting, spraying, and cultivating operations. Tractor axle load was approximately 4 Mg.
For the 1987 crop, year of reported measurements, secondary spring tillage was done on 28 April, corn was planted 29 April at 65000 seeds/ha. First cultivation was 29 May and second cultivation was 19 June. Samples from the continuous corn rotation were collected on 15 June. Samples from the corn plots in the corn-soybean rotation were collected 22 June. Only corn plots were sampled. Double ring infiltration measurements for the continuous corn and corn-soybean rotations were started immediately after sampling and it took 4 d to complete.

RESULTS AND DISCUSSION

Results presented in accompanying Figures and Tables show a response due to tillage, wheel-track, and crop rotation variables. The effect of crop rotation, however, may be confounded because of the second cultivation that occurred between measurements from the continuous corn and the corn-soybean rotations.

Tillage effect on bulk density (Table I), particularly in the 5-10 cm zone, is related to tillage intensity. As tillage intensity decreases from CONV to NTP, bulk density increases. This response is less evident with depth, but the NTP treatment does show an increase in density at the 30-35 cm zone for the continuous corn rotation. This may be the cumulative result of wheel traffic over time, but is unexpected because of the relatively low axle load applied to these trials. Effect of the wheel-track variable is apparent and will require consideration when evaluating tillage systems. For our system (four-row), every other interrow is wheel-tracked by 46 cm wide tires. Therefore, 30% of the area shows characteristics as described by the wheel-tracked interrow. The effect of crop rotation is not as apparent, but examination of the density within the 5-10 cm zone shows a reduction in density with the corn-soybean rotation, particularly in the nonwheel-tracked interrow NTP treatment. Density measurements may have been affected by cultivation, but measurements were taken below cultivation depth. A similar response was observed for clod densities collected from the surface layer (data not shown).

TABLE I

Bulk density by depth increment for the three tillage systems by nonwheel-tracked (NWT) and wheel-tracked (WT) interrows and crop rotation.

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>CONV NWT</th>
<th>CONV WT</th>
<th>RED NWT</th>
<th>RED WT</th>
<th>NTP NWT</th>
<th>NTP WT</th>
<th>LSD(.05)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous Corn Rotation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5-10</td>
<td>1.07</td>
<td>1.34</td>
<td>1.20</td>
<td>1.38</td>
<td>1.39</td>
<td>1.44</td>
<td>0.09</td>
</tr>
<tr>
<td>17-22</td>
<td>1.25</td>
<td>1.37</td>
<td>1.30</td>
<td>1.38</td>
<td>1.36</td>
<td>1.44</td>
<td>0.12</td>
</tr>
<tr>
<td>30-35</td>
<td>1.40</td>
<td>1.46</td>
<td>1.42</td>
<td>1.42</td>
<td>1.52</td>
<td>1.58</td>
<td>0.14</td>
</tr>
<tr>
<td>Corn-Soybean Rotation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5-10</td>
<td>1.06</td>
<td>1.31</td>
<td>1.09</td>
<td>1.28</td>
<td>1.18</td>
<td>1.36</td>
<td>0.08</td>
</tr>
<tr>
<td>17-22</td>
<td>1.27</td>
<td>1.41</td>
<td>1.35</td>
<td>1.39</td>
<td>1.28</td>
<td>1.35</td>
<td>0.08</td>
</tr>
</tbody>
</table>
As bulk density increases, total porosity will decrease. The decrease in total porosity comes primarily from reduction of macropore volume (pore size that drain at \( \leq 50 \) cm tension). Macropore volume, expressed as percent of total volume, are shown in Table II. Intermediate sized pores (drain at 50-600 cm tension) and micropore volumes were similar for all treatments (data not shown). The effect of tillage and wheel-track variables on macropore volume will influence both water and air transmission into the soil profile, important characteristics for water recharge and crop development.

Table II

<table>
<thead>
<tr>
<th></th>
<th>Tillage Systems</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CONV</td>
<td>RED</td>
</tr>
<tr>
<td></td>
<td>NWT</td>
<td>WT</td>
</tr>
<tr>
<td>Depth (cm)</td>
<td>Continuous Corn Rotation</td>
<td>% of Total Volume</td>
</tr>
<tr>
<td>5-10</td>
<td>20.2</td>
<td>6.5</td>
</tr>
<tr>
<td>17-22</td>
<td>11.2</td>
<td>5.2</td>
</tr>
<tr>
<td>30-35</td>
<td>7.9</td>
<td>8.5</td>
</tr>
<tr>
<td>5-10</td>
<td>21.9</td>
<td>7.1</td>
</tr>
<tr>
<td>17-22</td>
<td>11.0</td>
<td>4.0</td>
</tr>
</tbody>
</table>

Penetrometer resistance data examined at the same depth increments as bulk density and macropore volumes showed a greater strength with increased density and reduced macropore volumes (data not shown).

Cumulative aggregate size to 9 mm by tillage and wheel-track variables are shown in Fig. 1a for the continuous corn rotation and in Fig. 1b for the corn-soybean rotation. Differences due to wheel-track variable are observable in both crop rotations. Tillage differences are present in the continuous corn rotation for both wheel-track variables. Note the high percentage of aggregates > 9 mm in size for the nonwheel-track interrow NTP treatment (Fig. 1a). Tillage differences do not appear with the corn-soybean rotation and the NTP treatment shows a marked increase in percent aggregate ≤ 9 mm in size. Stability of the 1-2 mm aggregates is shown in Table III. Aggregates in general exhibit a high degree of stability, particularly considering that these samples were not premoistened. An increase in stability is observed in the wheel-tracked interrow and NTP treatments and a reduction in stability is observed for the corn-soybean rotation for the CONV and RED tillage treatments.

Infiltration data by the double ring infiltrometer method are shown in Table IV as average infiltration rate over the 3 h measurement period. High variability was observed with this procedure. Data obtained shows high infiltration for the CONV nonwheel-track interrow for both crop rotations and indicates a reduction in infiltration by all wheel-tracked interrows regardless of tillage. The nonwheel-track interrow for the NTP treatment continuous corn rotation shows relatively high infiltration which is not consistent with the observed macropore volume. Reduced infiltration for the nonwheel-track RED treatment cannot be explained.
The relatively low infiltration for the RED and NTP nonwheel-tracked treatments and very low infiltration observed by the wheel-track interrows in the corn-soybean rotation are also not understood and may be the result of soil sealing immediately below the sweep blade from the second cultivation.

![Graph](image)

**Fig. 1** Percent cumulative aggregate size to 9 mm for the three tillage systems by nonwheel-track (NWT) and wheel-track (WT) variables for A) continuous corn and B) corn-soybean rotations.

**TABLE III**

<table>
<thead>
<tr>
<th>Crop</th>
<th>Tillage Systems</th>
<th>CONV NWT</th>
<th>RED WT</th>
<th>NTP NWT</th>
<th>NTP WT</th>
<th>LSD(.05)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>% Stable</td>
</tr>
<tr>
<td>Continuous Corn</td>
<td></td>
<td>62.6</td>
<td>66.2</td>
<td>66.7</td>
<td>75.8</td>
<td>68.0</td>
</tr>
<tr>
<td>Corn-soybean</td>
<td></td>
<td>43.3</td>
<td>59.8</td>
<td>55.7</td>
<td>71.1</td>
<td>74.8</td>
</tr>
</tbody>
</table>

Tillage does have an effect on soil physical properties. Examination of the above data suggests that the conventional fall moldboard plow, spring disk tillage system results in the most desirable condition. However, crop rotational effects can be observed particularly in the NTP treatment. Soil properties are not static. High water runoff and soil erosion rates reported for northern Corn Belt soils (Mutchler et al., 1976) show that external energy (rainfall) can rapidly change surface properties of conventionally tilled systems. Ideally a tillage system can be devised that will include desirable properties from conventional tillage, but exhibit stability.
TABLE IV

Infiltration rates measured by the double ring method for the three tillage systems by nonwheel-track (NWT) and wheel-track (WT) interrows and crop rotation

<table>
<thead>
<tr>
<th>Crop Rotation</th>
<th>Tillage Systems</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CONV</td>
<td>RED</td>
<td>NTP</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>NWT WT</td>
<td>NWT WT</td>
<td>NWT WT</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Continuous Corn</td>
<td>31.3 5.7</td>
<td>6.2 3.8</td>
<td>15.5 5.6</td>
<td>9.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corn-soybean</td>
<td>21.6 0.3</td>
<td>5.1 1.6</td>
<td>4.1 0.5</td>
<td>7.1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Comparison of corn yields showed no significant differences at a yield level of 8.5 Mg/ha for the continuous corn and 10.0 Mg/ha for the corn-soybean rotation. A 5 to 7% yield reduction was observed with the NTP treatment in comparison with the CONV treatment for the two rotations. Similar yield reductions have been observed since initiation of these trials with the NTP treatment in the continuous corn rotation, but not with the corn-soybean rotation. These yield reductions are generally not significant indicating that while tillage can affect soil properties, these effects do not necessarily result in yield reductions.

CONCLUSIONS

1. Tillage, wheel-track, and crop rotation variables all have an effect on soil physical properties. However, properties measured at any point in time are subject to change due to influence of external forces.

2. When evaluating tillage systems, the amount of area covered by wheel traffic must be considered. The most consistent and largest effects on soil properties were from the result of wheel traffic. Tillage systems did not greatly influence the effects of wheel traffic on soil properties.

3. Crop yield was most affected by rotation. The yield response did not appear to be strongly related to the effect of rotation on soil properties. Although tillage had a great effect on soil properties, the effects on yield were minimal.

REFERENCES


THE HISTORY AND DEVELOPMENT OF TILLAGE IMPLEMENTS AND METHODS IN CHINA

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ABSTRACT

The history and development of tillage implements and methods in China, from the primitive society to now, are described in this paper. The role of these activities in the development of Chinese agriculture and society is also discussed. This paper briefly introduces the basic research work on tillage implements in China.

INTRODUCTION

China is a great and ancient agricultural country in the world. More than 80% of the population (8.38 hundred million) are farmers (1984). Agriculture is the main part of Chinese national economy. The income from agriculture is 2,629.2 hundred million Yuan, about 31.71% of total income from industry and agriculture in 1982.

There are more than 15 hundred million mu (One hundred million hectare) of cultivable land in China. That is, 1.5 mu (0.1 hectare) per person. The main grain crops are rice, wheat, potato, corn, sorghum, soybean and cereal crops. Cotton, oil, sugar, tobacco and medical materials are the main cash crops.

The tillage technique plays an important role in the agricultural production. The development of the tillage implements and methods promoted the development of agriculture and society. A further study of the development of Chinese tillage implements and methods will be of great immediate significance to the realization of agricultural modernization with Chinese characteristics.

THE TILLAGE IMPLEMENTS AND METHODS IN PRIMITIVE SOCIETY

China is considered as one of the earliest birthplaces of mankind. More than 170 million years have passed since Yuanmou Man. China is also one of the countries with a long agricultural history in the world. The Chinese agriculture began approximately 8,000 years ago in the early part of the New Stone Age in primitive society. The invention and development of farm implements played important roles in the development of Chinese agriculture. The invention and development of tillage implements stimulated the invention and development of farm implements. Someone said: "The ancient farm implements are the measure of the agricultural development and the indicator of the production relations in China". If this is true, we can say that the development of tillage implements is the mark of this indicator.

In primitive society, the earliest agricultural production was the simulation of the process of growing of plants in nature. People gathered seeds of grain crops, spread them on land, let them
grow naturally and harvested them after they were ripe. When people became familiar with the use of fire, they burnt the weeds and spread seeds on land. Lei, a digging tool including a wood rod with a sharp tip was then invented. After burning the weeds, the Lei was used to loosen the soil and dig holes for seeding. The next step included the invention of a two pronged Lei. It can be seen from the stone carving "Shen Nung Zei Lei Thu" (Fig. 1) which was carved in Han Dynasty (B.C.206 - B.C.220). A short rod on the Lei was soon added realizing that additional digging force could be applied with the foot.

A second digging tool Ssu constructed of stone followed the Lei. The earliest Ssu consisted of a polished stone without handle (Fig.2 a). Later, the Lei and Ssu were attached together as shown in Fig.2 b and it was known as Lei Ssu or Ssu.

The invention and development of both Lei and Ssu played an important role in the Chinese primitive agriculture and it is considered as an important step in Chinese agriculture history. It was Lei and Ssu that changed the Chinese primitive agriculture from the stage of Slash and Burn Cultivation to the stage of Lei and Ssu Cultivation which lasted for several thousand years.

In primitive agriculture, the tillage method developed from Liao Huang Zhi to lie fallow method. Liao Huang Zhi, or called primitive tillage method, was such a method that farmers moved and planted on a new land after they planted crops on a land for several years and the soil fertility was exhausted. With the lie fallow method, the land was lain fallow for one or two years after it was planted for several years.

THE FIRST GREAT REVOLUTION OF CHINESE TILLAGE IMPLEMENTS

Shang Dynasty (about B.C.1600 - B.C.1100) and Zhou Dynasty (about B.C. 1100 - B.C. 256) were the transition period in which the Chinese agriculture developed from a primitive agriculture to a traditional agriculture with intensive and meticulous farming as its main feature. Besides using Lei and Ssu, farmers invented intertillage implements, such as iron spade and swan-necked hoe.

Spring and Autumn Period (B.C.770 - B.C.476), Warring States Period (B.C.475 - B.C.221) and Qin Dynasty (B.C.221 - B.C.207) were the beginning of traditional Chinese agriculture. The first great revolution of Chinese farm implements was during this period. The main improvement was the use of oxen and iron farm implements for ploughing. The iron farm implements became popular in Spring and Autumn Period and took a dominant
position in the middle period of Warring States. The farm implements most commonly used were Lei, plough, spade with two blades, mouldboard, shovel, five-tine hoe and sickle. The plough in particular was an important revolution of the tillage technique.

Lei Ssu became the basis for the development of plough as illustrated in Fig. 3. "Paired Tillage" took a great role in this development process. Initially, one person held the Lei Ssu while another person pulled the Lei Ssu with a rope, raised the Lei Ssu and turned the soil over (Fig. 3 a). This procedure was changed and the person pulling the Lei Ssu pulled it forward continuously and turned the soil over continuously (Fig. 3 b). Lei Ssu was further modified to include a forward inclination and curved handle. Thus, the original shape of plough (Fig. 3 c) evolved from Lei Ssu.

The first plough was V-shaped and had no mouldboard. It had a sharp straight edge to break soil and make a ditch. It underwent continuous development and the ploughs shown in Fig. 4 are described in the Nung Shu (Agricultural Treatise). They are similar to those used in China before liberation.

Along with the development of iron plough, the tillage method with oxen was paid more and more attention and got large-scale extension in Warring States Period, Qin and Han Dynasty. The productivity increased because of the use of oxen and iron plough. The invention and extension of the tillage method with oxen and the iron plough had an epoch-making significance.

In this period, farmers adopted tillage practices for full utilization of land and to conserve the soil. In Spring and Autumn Period and Warring States Period, Ridge Culture was popular. Farmers made ridges on land and planted xerophyte on the ridges or crops with high water requirement in the furrows. In West Han Dynasty (B.C.206 - 24), Strip Culture was widely used. Farmers made ridges and furrows of 0.33 m deep and 0.33 m wide. In the first year, farmers planted crops in the furrows and scraped weeds and soil on the ridges to cover the root of crops. Second year, the ridges and furrows location were switched and crops were raised as described earlier. Later, Strip Culture was developed to Block Culture. Farmers separated land to blocks and planted crops in furrows.

Land preparation for Strip Culture required that farmers used "Paired Plough" with two oxen and three persons. One person led the oxen, one pressed the beam of plough and another handled plough. This procedure helped to increase the productivity considerably, for example, the productivity of 10 Han mu per person per day with the Lei Ssu increased
to 160 Han mu per person per day or more with Paired Plough. For "Paired Plough ", the oxen were connected to the plough with the method "two oxen carrying a lever ". In East Han Dynasty (25 - 220), farmers led ox with ox ring, ox rope and used ox yoke so that the force pulling plough was increased and the direction of plough was easier to control. Later, the tillage method was developed into "one person with two oxen ".

THE SECOND GREAT REVOLUTION OF CHINESE TILLAGE IMPLEMENTS

The greatest achievement of tillage implements in Tang Dynasty (618 - 907) was the invention of curved beam plough. With the replacement of straight beam with curved beam plough, the length of the plough was shortened. The plough frame was smaller and it weighed less. The tillage method of intensive and meticulous farming was paid more and more attention in this period. In northern part of China, farmers used the practices of tilling, harrowing and leveling to conserve moisture and soil. The animal powered square harrow (Fig.5) and V-shaped harrow (Fig.6), the iron-tined implement and the bush-harrow (Fig.7) made from wood strips were used for farming. In the southern part of China, besides using the plough and harrow, farmers used the vertical harrow (Fig.8) and ovoid roller (Fig.9) to break and level soils.

The second great revolution of farm implements in China was during Song Dynasty (960 - 1279) and Yuan Dynasty (1279 - 1368). In this period, many changes took place. Utilization of power, improved farm implements, increased variety of crop and increase in area cultivated are examples of changes occurred. There were more than 100 different types of farm implements. These included a variety of implements for ploughing and soil preparation and implements for cultured practices. In Ming (1368 - 1644) and Qing Dynasty (1644 - 1911), the farm implements were further improved and developed. They were diversified and small implements were used in small-scale agricultural production.
In the last of Qing Dynasty, wood ox (Fig. 10) was invented. While operating, two sets of wood ox were put on both ends of field, a rope was wound on the rollers of wood ox and a steel ring was tied on the rope to pull the plough. Two persons sat on the wood ox fames and turned round the rollers, one person hold plough in field. The plough could go there and back in field. The wood ox may be an embryonic form of modern cable-drawn plough.

In the long history of traditional agriculture in China, intensive and meticulous cultivation technology was its main feature and it continues even today, especially in rice production. Following is a sequence operations employed in soil preparation before rice transplanting, which is used in the paddy-fields grown with green manure crops:
1. Plough the field into blocks with 4-5 m wide and large clods;
2. Longitudinal harrowing using iron-blade harrow to break clods;
3. Second ploughing for leveling the bottom of the field to prevent water leakage;
4. Cross harrowing using iron-tine harrow to further break soil;
5. Third ploughing to cover the manure in the bottom of the field;
6. Cross harrowing using fine iron-tine harrow to break soils;
7. Longitudinal harrowing using wide wood-tine harrow to level soils;
8. Rolling with iron or wood roller;
9. Scraping;
10. Rice transplanting.

THE FORM AND DEVELOPMENT OF MECHANICAL TILLAGE SYSTEM IN CHINA

Agricultural mechanization and use of mechanical tillage system began after the liberation in 1949. Now, 40% of tillage operation in China are mechanized. A variety of farm implements were developed. The dry land tillage implement series and the paddy-fields tillage implement series were gradually formed. In order to meet the different tillage purpose in different soils, the different ploughs and disks with different kinds such as direct-mounted, semi-mounted, drawn and oscillated type were developed. A special tractor--Boat Tractor (Fig. 11) was invented and developed, which is special useful for paddy-fields. This Boat-Tractor has a boat bottom with a large contact area so that its contact pressure is less than 0.1 kg/cm², the sinkage is also small even in very soft soils and its resistance is decreased greatly. The Boat-Tractor has two driven wheels to produce drawbar force needed for useful work.

Basic research to improve the productivity of tillage implements, to decrease the power consumption and to improve the operating quality
of tillage implements is currently in progress, such as the forming theory of the plough bottom surface, the analytic method of plough bottom surface design, the power consumption of the plough bottom, the interaction of tillage implement with soil, the measurement and study on the ratio of ploughing resistance, the study on the methods decreasing the friction and adhesion on the plough surface with electro-osmosis and special coating, the measurement and study on the soil strength, the study on soil compaction and the controlled traffic farming. The experiment equipments used to study the relationship between tillage implements and soils, such as soil bin, were built and developed in many universities and research institutes. The study and development of measurement methods and apparatuses of tillage implements are sped up.

The study on the effect of different tillage methods on the soil structure and crop yield is also conducting. In paddy-fields, the rotary tillage is being extended and gradually instead of ploughing. The investigation on no-tillage and reduced tillage are being in progress.

From the review of the history and development of Chinese tillage implements and methods, we can see the great role of the tillage implements and methods in the development of Chinese agriculture. To sum up and study the experiences of the development of Chinese tillage implements and methods and integrate the traditional agriculture with modern science and technology will speed up the development of the modern agriculture in China.

ACKNOWLEDGEMENTS

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THE EFFECT OF CULTIVATION ON THE GROWTH AND DEVELOPMENT OF WINTER BARLEY

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ABSTRACT

A trial was set up in the autumn of 1983 in the north-east of Scotland to investigate the effect of four cultivation treatments; normal ploughing, shallow ploughing, discing and rotaspiking on crop development, root growth and on yield of Igri winter barley. The experiment ran for three seasons during 1983-1986, over a range of seasonal climatic conditions. The topsoil (0-300 mm depth) of the experimental site was a sandy silt loam overlying a sandy loam subsoil.

Cultivation affected moisture release characteristics, soil strength and bulk density. There was a higher macroporosity, lower bulk density and lower soil strength in the 100-300 mm zone of soil in the normal ploughed than in the rotaspiked treatment. In 1984/85 root growth in the spring/summer closely followed the pattern of soil strength, with most roots present in the topsoil of the normal ploughed soil. This led to a greater production of top material throughout most of the growing season. However, at the end of the season final yields were not influenced by cultivation method. This was also found in the 1983/84 and 1985/86 seasons, covering a range of weather conditions.

INTRODUCTION

Previous work has focused attention on reduced cultivation techniques both in connection with the need for timely sowing, economics and to protect soil from compaction and erosion. Despite initial poor yields under direct drilling in some experimental work, and understandable fears that these techniques were not suited to the Scottish climate, areas have been identified where this management technique might be successful (Pidgeon and Ragg, 1979).

Restriction of root growth can have important consequences for crop development. Although some work has been done on root growth in relation to reduced cultivation in Scotland (Ball and O'Sullivan, 1987 and Holmes, 1976), none has been in the northern Scottish climate.

This paper examines the effects of cultivation techniques on the soil physical condition and its subsequent effect on root and top development, and, ultimately, on yield.
MATERIALS AND METHODS

Site and soil

A site was selected at Tillycorthie farm (NJ 909235) in 1983 which was used for the three year trial period to investigate the effects of four cultivation treatments: normal ploughing (250-280 mm), shallow ploughing (150 mm), discing (two passes) (20-50 mm) and rotaspiking (20-120 mm), together with autumn nitrogen treatments (RIFT, 1983/84) on the yield of Igri winter barley. A split plot randomised block design with four replicates was used. Cultivation depth of each treatment varied in each trial year because of soil conditions at the time of cultivation.

In each of the three trial years of 1983, 84 and 85 the layout of the trial was identical with the four cultivation treatments being on the same main plots which measured 25 m x 8.52 m. This was done in order to find out if reduced cultivations carried out over successive years had any detrimental effect on crop growth and yield.

The area has around 800 mm of rainfall per annum and lies within the fairly warm, moist lowland climatic zone (Birse and Dry, 1970). The soils are free-draining brown forest soils (Dystric Cambisols (FAO)) and have a sandy silt loam texture in the topsoil. The underlying subsoil varied in texture from a sandy loam to a sandy silt loam and was indurated.

In the dry autumn of 1983 the site was burned to remove straw and stubble but in 1984 and 85 straw was removed and stubble was incorporated by treatments. The trial was sown on the 1 September in 1983 after a previous winter barley crop, on the 21 September in 1984 and on 12 September in 1985 at a seed rate of 470 viable seed/m². A basal fertilizer (19:90:90 kg NPK/ha) was combine drilled, additional spring nitrogen of 200 kg/ha was top dressed.

Soil and plant measurements

Soil cores were collected at 50 mm intervals throughout the topsoil for bulk density and moisture release measurements. Soil strength was measured using a Bush recording penetrometer (Anderson et al., 1980). Also, the crop was sampled at fortnightly intervals by harvesting half metre square areas and the dry matter content assessed. Plant establishment was determined as was the final grain yield in all three years. Root cores were collected at fortnightly intervals using a power drill (Welbank et al., 1974). Root growth assessments were also made using the profile wall method (Böhm, 1976) in 1984/85.

RESULTS

Soil physical properties

Figure 1 shows that the topsoil bulk density was lower under normal ploughing than rotaspiking to a depth of 250 mm (plough depth). The other two treatments were similar to the rotaspiked treatment.
In the 0-50 mm depth zone, the disced treatment had more available water in the 5 to 200 kPa pressure range than the other treatments and the normal ploughed treatments had the lowest available water over this range. However, at 150 to 200 mm depth, the disced and rotaspiked treatments had the least water available in the 5 to 200 kPa range. By 250 mm depth, all treatments had a similar moisture release characteristic.

Soil strength measurements were plotted against depth. In general, the strength of the normal ploughed soil was less than the others throughout the growing season, although there was an overall increase as the soil dried out (Figs. 2 and 3).

**Root growth**

Although most roots were in the top 150 mm of soil, roots had penetrated to 400 mm by the beginning of March (Fig. 4). It was not until April that differences in root number could be found. Thereafter until the end of the growing season, there were considerably more roots in the normal ploughed profile than in the other treatments with the least in the rotaspiked soil (Fig. 5).

**Top growth**

The normal ploughed treatment showed greater top growth than the other three from March until June, with the rotaspiked treatment giving lowest yields (Fig. 6).

**Plant establishment**

In 1983/84 when cultivations were carried out during dry conditions, there was lower plant establishment on the rotaspiked and shallow ploughed treatments (Table I). This difference in plant establishment between cultivations was not reflected in yield (Table II), with fairly high yields recorded, due to the good weather conditions that year.

**Table I. Effect of cultivation on plant establishment (plants/m²)**

<table>
<thead>
<tr>
<th>Cultivation</th>
<th>Normal ploughing</th>
<th>Shallow ploughing</th>
<th>Discing</th>
<th>Rotaspiking</th>
<th>Treatment means</th>
<th>SED</th>
</tr>
</thead>
<tbody>
<tr>
<td>1983/84</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>413** (NP&gt;SP and R)</td>
<td>24</td>
</tr>
<tr>
<td>1984/85</td>
<td>336</td>
<td>390</td>
<td>397* (R&gt;NP)</td>
<td></td>
<td>396</td>
<td></td>
</tr>
<tr>
<td>1985/86</td>
<td>396</td>
<td>335</td>
<td>370</td>
<td>353</td>
<td>396</td>
<td></td>
</tr>
</tbody>
</table>

* P < 0.05  ** P < 0.01
Table II. Effect of cultivation on grain yield at 15% MC (tonnes/ha)

<table>
<thead>
<tr>
<th>Cultivation</th>
<th>Normal ploughing</th>
<th>Shallow ploughing</th>
<th>Discing ploughing</th>
<th>Rotaspiking</th>
</tr>
</thead>
<tbody>
<tr>
<td>1983/84</td>
<td>8.51</td>
<td>8.63</td>
<td>8.61</td>
<td>8.66</td>
</tr>
<tr>
<td>1984/85</td>
<td>5.56</td>
<td>5.54</td>
<td>5.63</td>
<td>5.56</td>
</tr>
<tr>
<td>1985/86</td>
<td>8.12</td>
<td>8.18</td>
<td>8.35</td>
<td>8.19</td>
</tr>
</tbody>
</table>

In 1984/85 the whole year was considerably wetter than average and there was a less than average number of hours of sunshine. This led to low final yields on all treatments (Table II). Plant establishment was lower in the normal ploughed than in the rotaspiked soil.

In 1985/86 there were no significant differences between cultivations in either plant establishment or yield.

DISCUSSION

The lower bulk density and soil strength found in the ploughed soil compared with the other treatments confirm the findings of Ball and O'Sullivan (1987). After April, the pattern of root distribution with depth was closely related to soil strength, with most roots being found in the topsoil of the normal ploughed soil, and least in the rotaspiked soil. Holmes (1976) found that root growth was inhibited under reduced cultivation (direct drilling) because of mechanical impedance, and that root length in different horizons was closely related to bulk density. Ball and O'Sullivan (1987) also found, in June, more roots in the top 200 mm of soil ploughed to 250 mm than in direct drilled soil.

Top development reflected the greater ease of soil exploitation in the normal ploughed soil. The greater top production in the normal ploughed soil continued until July.

However, final grain yields in 1984/85 were not affected by cultivation treatment. The same result was found in the 1983/84 and 1985/86 seasons. No matter what seasonal weather conditions were, grain yields were unaffected by cultivation treatment. In the light of results found here, in the North-East of Scotland, it suggests that alternative methods of cultivation are, in the short term, giving comparable yields, despite differences in the soil physical environment and root and top development.
CONCLUSIONS

1. There was no effect of cultivation on final yield of grain in all 3 contrasting seasons studied.
2. Yield was unaffected by soil conditions at plant establishment.
3. Normal ploughing allowed a better development of tops throughout most of the growing season.
4. The pattern of root distribution reflects soil strength in the spring with most roots in the normal ploughed soil and least roots in the rotaspiked soil.
5. Normal ploughing gives a lower bulk density, higher porosity and lower soil strength than shallow ploughing, discing and rotasping does.

ACKNOWLEDGEMENTS

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Fig. 1  Bulk density vs depth

Fig. 2  Soil strength vs depth 10/3/85

Fig. 3  Soil strength vs depth 28/5/85

Fig. 4  Root number vs depth 10/3/85

Fig. 5  Root number vs depth 28/5/85

Fig. 6  Seasonal top growth
INTERACTION BETWEEN SOIL TILLAGE AND GREEN MANURING IN A WINTER WHEAT-MAIZE CROP ROTATION

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ABSTRACT

The study of the interaction between soil tillage and green manuring in a winter wheat-maize crop rotation was the objective of a long term field experiment on a clay (28%) soil from 1972 to 1986.

The main conclusions are that minimum tillage (5-10 cm) is a suitable technique to sow wheat after maize and maize after wheat. Some restrictions are made concerning the weed and insect control. From the agronomic point a view, green manure is not efficient enough to get higher grain yields, especially when incorporated by ploughing. Between the tilled and no-tilled plots, changes in the chemical soil properties have occurred but did not affect the grain yields.

OBJECTIVES

This field experiment was started in autumn 1971 in Changins (430 m) to answer the following farmers' questions:

- Is it necessary to plough before sowing wheat and maize in rotation?
- Can any green manure diversify such a simplified crop rotation?
- What is the nitrogen fertilizing effect of green manure?
- What are the long term effects of no-tillage and green manure on the chemical soil properties?

SITE AND EXPERIMENT

. Soil 0-30 cm : 28 % clay (0-2 μm), 42 % silt (2-50 μm), 30 % sand (50 μm-2 mm)

. Crop rotation : Winter wheat-maize. The wheat straw is baled; the maize stalks are left on the field.

. Green manure : Mustard (30 kg/ha) + 40 kg N/ha after seeding (each second year after wheat)
Trial design: Split plot with 4 replications

Main treatments:
- \( P \): Autumn ploughing (20-25 cm) (8 x 26 m)
- \( P+GM \): Autumn ploughing + green manure
- \( MT \): Minimum tillage (5-10 cm) just before seeding
- \( MT+GM \): Minimum tillage + green manure

Sub treatments:
- \( N1 \): 80 N/ha wheat; 110 N/ha maize (4 x 26 m)
- \( N2 \): 120 N/ha wheat; 150 N/ha maize

RESULTS AND CONCLUSIONS

1. Minimum tillage (5-10 cm) can be recommended to the farmers to sow winter wheat after maize and maize after winter wheat in normally draining clay soils (Fig. 1+2+3). If used each year, this tillage technique needs some more chemical weed control, especially against grasses. In regions where the maize stem borer (Ostrinia nubilalis) is present, we cannot recommend to sow wheat after maize by minimum tillage because the maize stalks left at the soil surface contribute to a spreading of this insect. The incorporation of the maize stalks by ploughing has been proved to be a simple biological method of getting rid of this insect.

2. Green manure (mustard), sown after the wheat harvest, did not ameliorate the maize and wheat grain yields, especially when the incorporation of this green matter takes place in autumn by ploughing (Fig. 2+3). The efficiency of the 40 kg N/ha (mineral) spread in the spring time just after seeding maize is better than the 40 kg N/ha given to the green manure in the summer time (Fig. 2). From the ecological point of view, seeding any green manure in the summer time is a valuable technique especially when the soil is bare until the spring time. The green manure prevents both nitrogen leaching and soil erosion over the winter.

3. Ploughing is an excellent technique to mix both the soil and the fertilizers. The values of pH, \( P_2O_5 \), \( K_2O \) and organic matter are rather even in the tilled soil layers (Fig. 4+5+6+7).

4. After 15 years of minimum tillage, a clear acidification and an important accumulation of phosphorus, potash and organic matter have taken place in the upper soil layers in comparison with the ploughed plots (Fig. 4+5+6+7). In the deeper layers (15 to 25 cm), the phosphorus and potash concentration have decreased on the contrary. The modifications of these soil chemical properties affected neither the emergence nor the growth of wheat and maize.

5. Green manure, grown 6 times between 1975 and 1986, increased the organic matter content of the soil only when it was incorporated in the upper layers with minimum tillage (Fig. 7).
Fig. 1. Relative grain yield compared to the fall ploughing (P) treatment (Crop rotation: winter wheat-maize since 1972)

Fig. 2. Average relative maize grain yield of 5 harvestings, 1977-1985 (100% = 5.7 t/ha)
Fig. 3. Average relative winter wheat grain yield of 6 harvestings, 1976-1986 (100% = 4.5 t/ha)

Fig. 4. Soil pH-value (1986) after 15 years of continuous tillage and green manure management practices
Fig. 5. Soil $P_2O_5$ - Index (1986) after 15 years of continuous tillage and green manure management practices (Index $I = 0.0356$ mg $P_2O_5$/100 g soil)

![Diagram showing soil $P_2O_5$ index](image)

$P =$ PLough
$MT = $ MINIMUM TILLAGE
$GM = $ GREEN MANURE

Mean (0-25cm)
- $P = 12.9$
- $P + GM = 8.7$
- $MT = 17.7$
- $MT + GM = 19.4$

Fig. 6. Soil $K_2O$ - Index (1986) after 15 years of continuous tillage and green manure management practices (Index $I = 1$ mg $K_2O$/100 g soil)

![Diagram showing soil $K_2O$ index](image)

$P = $ PLough
$MT = $ MINIMUM TILLAGE
$GM = $ GREEN MANURE

Mean (0-25cm)
- $P = 0.85$
- $P + GM = 0.68$
- $MT = 0.90$
- $MT + GM = 0.96$
Fig. 7. Soil organic matter content (1986) after 15 years of continuous tillage and green manure management practices (O.M. = organic C x 1.72; % w/w)
THE USE OF EXPERT SYSTEMS TO PROVIDE CONSERVATION TILLAGE RECOMMENDATIONS

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ABSTRACT

A region-level set of decision rules is being developed to provide conservation tillage recommendations to farmers in the eastern Corn Belt of the U.S. The initial program, called "TESTOP" is the first module of an Expert systems development that, eventually, will help in deciding which tillage system is most appropriate for a given farming operation. An important step in reaching that goal is to have a method of estimating realistic production potentials for various tillage systems with various rotations in specific fields, each of which may contain various soils. TESTOP provides that method. It estimates annual production for a field of maize (Zea Mays L.) soya bean [Glycinemax (L) Merr.], in continuous or rotation cropping patterns, for six alternative tillage systems: fall plow, fall chisel, spring plow, spring disk, ridge-till and no-till. To do so, TESTOP requires user-input regarding crop, rotation, and field location (latitude), plus the soil types and area (hectares) of each soil type in the field.

INTRODUCTION

There is a need, not only to find research solutions to production-management problems facing farmers but to make this technology transfer readily available to them. One approach for achieving this goal is to develop a system that assists non-experts in reaching expert conclusions, and explain these conclusions to the satisfaction of the user without the presence of an expert. To be effective, this program should be adapted to very low level computers, the costs for the program must be low, explanations must be given in understandable language, and it must run fairly fast.

BACKGROUND

Information presented is not based entirely on individual experiments, although research has played a major role in the development of the knowledge base of "experts". In addition to the research, the decision making process outlined in the system also makes use of experiences of extension specialists and farmers. Recommendations included in TESTOP (Tillage Expert System to Optimize Production) (Meyer, et al. 1987) are most appropriate for the eastern Corn Belt states of Indiana, Illinois, and Ohio, but with slight modifications in yield relationships and for cultural practices, could be used in a broader area.
Based on research (Griffith and Mannering, 1985) and farmer experience over the past twenty years, performance of conservation tillage systems has been found to be closely tied to soil drainage, crop sequence, length of growing season, fertilization, pest problems and skills and attitudes of the farmer. However, the TESTOP module includes only drainage, some soil properties, crop sequence and length of growing season in the decision making process.

Soil drainage - Generally as the drainage improves, the need for tillage decreases. Wet soils are cold soils and surface cover associated with conservation tillage tends to keep soils colder longer in the spring.

Crop sequence - Conservation tillage systems perform better in crop rotation than mono-culture. On poorly drained soils, those crops that produce less residue improve the success of systems such as no-till in the following crop year, due partially, to higher soil temperatures early in the growing season at middle Corn Belt latitudes.

Length of growing season - Tillage systems that leave most of the soil surface covered by residue such as no-till have generally been successful in the middle and southern latitudes of the Corn Belt on well-drained soils. In the northern states of Wisconsin, Minnesota and Michigan, as well as Canada, studies often show significant yield decreases when comparing no-till to clean tillage systems.

The objective for the development of TESTOP is to assist maize and soya bean producers in selecting which tillage system(s) is best adapted to their soils, cropping program and climate based on production potential.

PROCEDURE

Soil Tillage Management Groups. A central concept of TESTOP is the classification of soils into one of seven "Soil Tillage Management Groups" (Doster, et al., 1988). The purpose is to group soils that are expected to respond in a similar fashion to specific tillage systems. These groups are defined in footnote 2 of Table I.

The Soil Tillage Management Group is determined by identifying each soil type in the field from a detailed soil survey. For example, the physical characteristics of all the soils in Indiana are stored in a computer data file which TESTOP can use to determine the appropriate Management Group, given the name of the soil type. Where detailed soil surveys are not available the computer can still assign a soil to a "Group" if the user knows certain soil characteristics. (See Figure 1.)

Tillage Coefficients are assigned for each Tillage Management Group and represent the relative yields expected with each tillage system (Doster, et al., 1988). There are different coefficients for rotational and monocultural maize and soya bean. These coefficients shown in Table I are based in part on research results and in part on experience primarily from the eastern Corn Belt. Assigning Fall Plow a tillage coefficient of 1.00 for rotation maize and Ridge-Till a tillage coefficient of 1.03 (Group 4 in Table I), simply means that if the yield on the soil is known for Fall Plow, it can be multiplied by 1.03 to estimate the yield for Ridge-Till.
Table 1. Maize and Soybean Yield Coefficients for Tillage Systems\textsuperscript{1/}, Indiana Soils.

<table>
<thead>
<tr>
<th>Soil Group (2/)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
</tr>
<tr>
<td><strong>Rotation Maize</strong> (first year after soya bean)</td>
</tr>
<tr>
<td>Fall plow</td>
</tr>
<tr>
<td>Fall chisel</td>
</tr>
<tr>
<td>Spring plow</td>
</tr>
<tr>
<td>Disc or field cultivate</td>
</tr>
<tr>
<td>Ridge</td>
</tr>
<tr>
<td>No-Till</td>
</tr>
<tr>
<td><strong>Continuous Maize</strong></td>
</tr>
<tr>
<td>Fall plow</td>
</tr>
<tr>
<td>Fall chisel</td>
</tr>
<tr>
<td>Spring plow</td>
</tr>
<tr>
<td>Disc</td>
</tr>
<tr>
<td>Ridge</td>
</tr>
<tr>
<td>No-Till</td>
</tr>
<tr>
<td><strong>Rotation soya bean</strong> (first year after maize)</td>
</tr>
<tr>
<td>Fall plow</td>
</tr>
<tr>
<td>Fall chisel</td>
</tr>
<tr>
<td>Spring plow</td>
</tr>
<tr>
<td>Disc</td>
</tr>
<tr>
<td>Ridge</td>
</tr>
<tr>
<td>No-Till</td>
</tr>
</tbody>
</table>

\textsuperscript{1/} Tillage system descriptions include: Fall plow--fall mold board plowing, 1 to 3 spring passes to prepare seedbed. Fall chisel--same as fall plow, except a chisel plow is substituted for the mold board plow. Spring plow--same as fall plow, except mold board plowing is done in the spring. Spring disk or field cultivate, 1 to 3 spring passes with a disk or field cultivator to prepare seedbed. Ridge till--planting into wide tilled strips on pre-formed ridge tops; no other tillage operation at planting. No-till--planting into very narrow tilled strips through old-crop residue; no other tillage operation.

\textsuperscript{2/} Soil group descriptions:
1. Dark, poorly drained silty clay loams to clays, 0 to 2\% slope.
2. Light (low-organic matter), somewhat poorly drained silt loams to silty clay loams, nearly level to 4\% slopes.
3. Light (low organic matter), well and moderately well drained sandy loams to silt loams on 3 to 6\% slopes that are subject to slight to severe water erosion; and shallow terrace soils as well as coarse
textured soils (sands, loamy sands and sandy loams) that are subject to severe wind erosion and/or drought.

4 Light (low organic matter), well drained sandy loams to silt loams on slopes greater than 6% that are subject to very severe water erosion.

5 Light (very low organic matter), somewhat poorly and poorly drained silt loams, nearly level to gently sloping, overlying very slowly permeable fragipan-like pans that restrict plant rooting and water movement.

6 Dark, poorly drained, "high water table," loamy sands and sandy loams on 0 to 2% slope. Because of moderately coarse and coarse surface textures, these soils are subject to severe wind erosion and damage to young plants by blowing sand.

7 Muck, dark soils with greater than 30% organic matter, poorly drained, nearly level subject to severe wind erosion if left unprotected.

**Figure 1. Classification of soil into soil tillage management groups.**
For drainage P = poorly, S = somewhat, M = moderately well, W = well.

Base Yields for maize and soya bean are assigned to individual soil types based on research and experience. In Indiana a publication (Galloway and Steinhardt, 1981) is available that contains crop yield estimates for each soil in the state. Other states have similar information available. If this information is not available or if the users feel the reported yields are not representative of their fields, they may enter their own yield estimate for a specific tillage system and the program will compute yields for the other systems based on the tillage coefficients.

**Latitude Adjustments for No-Till.** In northern latitudes of the Corn Belt, No-Till yield estimates are decreased slightly due to the insulation effect of surface crop residue and resulting temperature reduction at planting. The adjustment is made through multiplication by "latitude factors" calculated as follows:
Im = D - 3100 + 1.0 and Ls = 0.4 (Lm - 1.0) + 1.0

where Im is the latitude factor for maize stubble, Ls is the latitude factor for soya bean stubble, and D is the number of degree-days during the growing season. TESTOP uses degree-day values for the period from May 10 to October 10, interpolated by county (Neild and Newman, 1986). Degree-days are computed using the average of the daily maximum temperature (not to exceed 30°C) and the daily minimum temperature, minus 10°C.

Production Estimate for the Entire Field. The production for each soil type within a field is estimated for each of the six tillage systems by taking the reported base yield for that soil times the appropriate tillage coefficient for the specific tillage system and soil tillage management group times the latitude factor. Once production is estimated for each of the soil types in the field, they are added together to produce the estimate for the entire field. The user is then given the opportunity to enter an observed yield or yield estimate, and all yield estimates from the various tillage systems are re-scaled accordingly. The maximum possible yield for the field is computed by allowing the best tillage system to be used on individual soil types and totaling the yields from this procedure. Then the production estimate from the best tillage system for the entire field is compared to the maximum possible yield. If production estimates for the best tillage system are not within 125 kg ha⁻¹ of the maximum possible for the field, a suggestion is made to split the field. In the context of this discussion a "field" is an area of land managed as a single unit and "soil type" is a portion of the field in which 90% of the area is of one soil phase.

An example of the production estimates from a 32.4 ha field containing 10.9 ha of Group 1, 10.9 ha of Group 3, and 10.5 ha of Group 4 soils is shown in Table II.

Table II. Projected Total Production (Mg) by Tillage (Maize/Soya Bean & Rotation).

| Tillage System  | Rotational Maize | | Rotational Soya Bean |
|-----------------|------------------|------------------|
|                 | Yield total production Mg | Yield total production Mg |
| Fall Plow       | 6.59 527.5       | 2.19 175.2        |
| Fall Chisel     | 6.79 542.8       | 2.26 180.7        |
| Spring Plow     | 6.79 542.8       | 2.24 179.2        |
| Spring Disk     | 6.79 542.8       | 2.26 180.7        |
| Ridge-Till      | 6.87 549.9       | 2.32* 185.7       |
| No-Till         | 6.97* 557.3      | 2.26 181.2        |
| Maximum Value   | 6.99 559.7       | 2.33 186.4        |

* Most productive system

Production Estimate for Entire Farm. TESTOP also summarizes total production of the several fields that comprise the entire farm. These
total production values permit the user to compare the production from the six tillage systems if each were used over the entire farm and then compare those production values with production from an idealized plan where tillage system use is optimized based on soil types.

SUMMARY

TESTOP is an "expert" system that will help in deciding which tillage system(s) is most appropriate and/or profitable for a given farming operation in which maize and soya bean are the principal crop. The information on which TESTOP is based is not primarily from specific results of individual experiments, but rather the knowledge and experience of both university specialists and farmers. This is the first of several modules to be developed and deals with the estimation of production. Other modules to follow will deal with soil erosion, equipment selection, fertilization, pest control, and, finally, economics. These modules will be interactive and should be very helpful to those users interested in obtaining "expert" advice in selecting the proper tillage system for their specific conditions.

REFERENCES


PERFORMANCE OF ZERO-TILLAGE IN WHEAT AND MAIZE PRODUCTION UNDER DIFFERENT SOIL AND CLIMATIC CONDITIONS IN NIGERIA

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ABSTRACT

Irrigated maize and wheat production though practiced through zero-tillage from centuries by traditional farmers along the river courses, is a relatively recent phenomenon receiving attention of the large scale irrigation projects in Nigeria. Experiments were conducted during 1982-85 on the sandy soil of Bakura (mean air temp. 22°C) and sandy loam soil of Kadawa (mean air temp. 18°C) to compare the zero-tillage with conventional tillage. Maize-wheat annual rotation on irrigated sandy loam soil, the practice of zero-tillage farming with the retention of adequate crop residue (5 to 6 t/ha) on the soil surface maintained the total annual crop production at Kadawa site. The annual crop production under zero-tillage was always lower than conventional tillage under sandy soil and dry climate of Bakura.

INTRODUCTION

Zero-tillage techniques along with residue on the surface are useful for crop production in the humid tropics where conventional tillage systems cause accelerated soil erosion (Lal, 1973; Maurya and Lal, 1979; Van Doren and Triplett, 1979). Plants grown in semi-arid tropics without tillage are stunted and show symptoms of water and nutrient deficiencies because of high surface soil bulk density, low porosity, retarded infiltration and low water-holding capacity of the soil (Huxley, 1979; Maurya, 1986) in absence of previous crop residue. In irrigated areas of northern Nigeria, maize and wheat in a yearly rotation provide sufficient residue for the next cropping season. The continuous use of residue from the preceding crop as mulch on undisturbed soil maintained the crop production under semi-arid climate (Ike, 1986).

However, in the region of high evaporative demand under low soil water holding capacity and low soil fertility condition, no-tillage cultivation may not maintain the soil at productive level. Therefore the objective of this study was to compare the effect of zero-tillage and conventional tillage on yield of maize-wheat annual rotation in the irrigated sandy and sandy loam soils of two different climatic zones of Nigeria.

MATERIALS AND METHODS

The field experiments reported here were conducted during 1982-85 at the Irrigation Research Stations at Bakura (12°
48°N, 5° 53'E) and Kadawa (11° 8'N, 8° 15'E). The climatic data of the two sites are given in Table I.

Table I. Meteorological data (five years mean) of the experimental sites.

<table>
<thead>
<tr>
<th>Month</th>
<th>Pan Evaporation (mm day⁻¹)</th>
<th>Minimum Air Temperature (°C)</th>
<th>Rainfall (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bakura</td>
<td>Kadawa</td>
<td>Bakura</td>
<td>Kadawa</td>
</tr>
<tr>
<td>Jan.</td>
<td>8.8</td>
<td>8.3</td>
<td>18.7</td>
</tr>
<tr>
<td>Feb.</td>
<td>10.7</td>
<td>9.1</td>
<td>16.9</td>
</tr>
<tr>
<td>March</td>
<td>9.1</td>
<td>8.1</td>
<td>21.5</td>
</tr>
<tr>
<td>April</td>
<td>10.0</td>
<td>8.7</td>
<td>24.3</td>
</tr>
<tr>
<td>May</td>
<td>9.1</td>
<td>8.6</td>
<td>28.6</td>
</tr>
<tr>
<td>June</td>
<td>9.2</td>
<td>8.4</td>
<td>29.0</td>
</tr>
<tr>
<td>July</td>
<td>5.9</td>
<td>5.5</td>
<td>24.0</td>
</tr>
<tr>
<td>Aug.</td>
<td>8.3</td>
<td>5.5</td>
<td>24.0</td>
</tr>
<tr>
<td>Sept.</td>
<td>6.0</td>
<td>8.9</td>
<td>23.0</td>
</tr>
<tr>
<td>Oct.</td>
<td>7.0</td>
<td>8.7</td>
<td>24.0</td>
</tr>
<tr>
<td>Nov.</td>
<td>7.0</td>
<td>7.5</td>
<td>15.0</td>
</tr>
<tr>
<td>Dec.</td>
<td>8.0</td>
<td>7.9</td>
<td>14.0</td>
</tr>
<tr>
<td>Mean</td>
<td>8.0</td>
<td>7.7</td>
<td>21.5</td>
</tr>
<tr>
<td>Total</td>
<td>842.4</td>
<td>660.2</td>
<td></td>
</tr>
</tbody>
</table>

The surface soil of experimental site at Bakura has sandy texture with high infiltration rate, 80-90 mm m⁻¹ available water holding capacity and low soil fertility status (Table II). The soil of Kadawa site is classified as Butric Cambisol (FAO/UNESCO) and Typic Ustropept (Soil Taxonomy Class) (Valette, 1978). The surface soil has a sandy loam texture with 130-150 mm m⁻¹ available water holding capacity. The hard iron pan at 120-150 cm depth periodically resulted in a perched water table between 30 and 120 cm depth throughout the year.

Two distinct growing seasons occur in the area: the irrigated cropping season, which runs from November to March, and the rainfed cropping season, which lasts from June to September. Generally, wheat is planted in the beginning of the cool dry season in mid November while maize is planted in mid June (after the rains). Conventional tillage consisted of disc ploughing (once for maize and twice for wheat) to a depth of 20 cm, followed by harrowing, whereas no mechanical seed-bed preparation took place in the zero-tillage system. Two weeks before planting the crop, the zero-tillage plots were treated with 1.4 kg ha⁻¹ glyphosate. The residue management treatments were, 1) previous crop residue left on the surface in the zero-tillage plots and incorporated in conventional tillage, and 2) previous crop residue removed from the plot, irrespective of tillage treatment. Fertilizer was applied at 60 kg ha⁻¹ N, 26 kg ha⁻¹ P, and 50 kg ha⁻¹ K for each crop before planting. Four weeks after planting a further 60 kg ha⁻¹ N were applied as a top dressing. Wheat (cv. Siete Cerros) was planted in rows 15 cm apart in the third week of November each year.
Maize (cv. TZB) was planted at 75 cm between the rows and 25 cm within rows in the second week of June each year. Few supplementary irrigations were provided for maize before the rain established and regular irrigation was provided for wheat. The plots were 4 m wide and 80 m long to facilitate the border irrigation and other mechanized operation. The weed infestation was monitored at flowering stage (after ten weeks of planting) of wheat. Weed samples were taken from each plot by removing all weeds from one square metre. These samples were oven dried at 85°C and dry matter weight were recorded. The grain yields of both crops were recorded at harvest.

RESULTS AND DISCUSSION

The mean annual grain production (maize and wheat yield) was lower at Bakura than at Kadawa (Fig.1). This was due to the high weed infestation and high water deficit at Bakura (1083 mm year⁻¹) than Kadawa (844 mm year⁻¹). The short duration of cool dry period (wheat growing period) by 20 percent at Bakura contributed toward the reduction in wheat grain yield. The maize grain yield was lower at Bakura (1.5 Mg ha⁻¹) than Kadawa (3.1 Mg ha⁻¹) due to less and uneven distribution of rainfall and low water holding capacity of soil (Table III and IV).

Bakura Site:

The mean grain yield of crops was in general lower in zero-tillage (2.7 Mg ha⁻¹ year⁻¹) than conventional tillage (3.8 Mg ha⁻¹ year⁻¹), under sandy soil (Table III). This was due to very low residue of previous crop to act as surface cover and low fertility and available water holding capacity of the soil. Also the conventional tillage successfully controlled the weed population and incorporated the residue and weeds with the soil. The weed infestation in wheat was 25 percent (Fig.2) higher in the zero-tillage (258 g m⁻²) than conventional tillage (205 g m⁻²). The incorporation of residue in the tillage plot produced higher grain yield than left on the surface as mulch under zero-tillage. The effects of residue as mulch was non significant on weed control and grain yield.
Kadawa Site:

Wheat yield was significantly affected by tillage treatments in the first but not in the second and third cropping season (Table IV). The yield in the first year was significantly higher in the zero-tillage plot than in the conventional tillage plot. Averaged for the three years, the mean wheat yields were 3.88 and 3.60 Mg ha\(^{-1}\) in the zero and conventional tillage, respectively. The weed dry weight was higher in conventional tillage (148 g m\(^{-2}\)) than zero-tillage (123 g m\(^{-2}\)) at flowering stage of wheat (Fig. 2).

Table III: Grain yield of maize and wheat (Mg ha\(^{-1}\)) as affected by tillage and residue treatments during 1983-85 cropping season at Bakura.

<table>
<thead>
<tr>
<th></th>
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<th></th>
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</thead>
<tbody>
<tr>
<td>Zero-tillage</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Residue</td>
<td>1.26</td>
<td>1.27</td>
<td>1.14</td>
</tr>
<tr>
<td>No-residue</td>
<td>1.56</td>
<td>1.26</td>
<td>1.21</td>
</tr>
<tr>
<td>Mean</td>
<td>1.41</td>
<td>1.28</td>
<td>1.18</td>
</tr>
<tr>
<td>Conventional tillage</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Residue</td>
<td>1.90</td>
<td>1.87</td>
<td>2.13</td>
</tr>
<tr>
<td>No-residue</td>
<td>1.50</td>
<td>1.54</td>
<td>1.81</td>
</tr>
<tr>
<td>Mean</td>
<td>1.70</td>
<td>1.70</td>
<td>1.92</td>
</tr>
</tbody>
</table>

L.S.D. (5%)

<table>
<thead>
<tr>
<th>Tillage</th>
<th>0.41</th>
<th>0.42</th>
<th>0.38</th>
<th>NS</th>
<th>NS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residue</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

Fig. 1. Mean annual grain production (1982-85) as affected by tillage at Bakura (Sandy soil) and Kadawa (Sandy loam soil).
Table IV  Maize and wheat yield (Mg ha\(^{-1}\)) as affected by tillage and residue management practices during the 1982-1984 at Kadawa.

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Zero-tillage</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Residue</td>
<td>3.3 3.8</td>
<td>4.0 3.3</td>
<td>2.3 4.4</td>
</tr>
<tr>
<td>No-residue</td>
<td>3.4 3.7</td>
<td>2.8 3.8</td>
<td>1.9 4.2</td>
</tr>
<tr>
<td>Mean</td>
<td>3.4 3.8</td>
<td>2.9 3.5</td>
<td>2.1 4.3</td>
</tr>
<tr>
<td>Conventional tillage</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Residue</td>
<td>4.1 3.0</td>
<td>3.9 3.8</td>
<td>2.2 4.4</td>
</tr>
<tr>
<td>No-residue</td>
<td>4.0 3.1</td>
<td>3.9 3.6</td>
<td>2.2 3.6</td>
</tr>
<tr>
<td>Mean</td>
<td>4.1 3.1</td>
<td>3.8 3.8</td>
<td>2.2 4.0</td>
</tr>
</tbody>
</table>

L.S.D.(5%) Tillage 0.28 0.18  NS NS NS NS NS
Residue NS NS NS NS NS NS

NS, Non-significant

The effect of residue treatments were only significant in the third wheat crop. In general, wheat yield was higher in the residue plots irrespective of tillage treatment and in the third crop the residue treatment gave a significantly higher yield (4.4 Mg ha\(^{-1}\)) than the no-residue treatment (3.9 Mg ha\(^{-1}\)). This is due to the cumulative effect of organic matter in the soil.

Fig. 2. Effect of tillage and residue treatments on weed infestation at flowering stage of wheat (mean of 1983 & 1984)

The maize yield for the 1984 cropping season was lower than the two previous years. Which was due to uneven distribution and less rainfall during the cropping season (June to September) in 1984 (447 mm) than in 1982 (525 mm) and
1963 (546 mm). The tillage effect was significant in the grain yield of the first year, whereas the effect was non-significant in the subsequent years. During the first crop of maize the grain yield was significantly higher in the tillage plots, though the relative increase was non-significant. The mean yield of the three cropping season was higher in the conventional tillage plots (3.4 Mg ha\(^{-1}\)) than in the zero-tillage plots (2.8 Mg ha\(^{-1}\)). This may be due to higher weed infestation in the zero-tillage plots. Over the three cropping seasons, the mean grain yield was slightly higher in the residue plots (3.3 Mg ha\(^{-1}\)) than in the no-residue plots (3.2 Mg ha\(^{-1}\)).

CONCLUSIONS

1. The total annual crop production in the zero-tillage was always lower than the conventional tillage in low fertile sandy soil of Bakura.

2. Maize-wheat annual rotation at Kadawa provided sufficient residue from the preceding crop to act as mulch and maintained the production level in the Eutric Cambisol with the zero-tillage.

3. The major problem of zero-tillage in this region is inadequate weed control. A reliable weed control method has to be identify to achieve the full benefit of zero-tillage.

REFERENCES


ABSTRACT
Objective selection of the best planters or drills for a particular farmer's needs may be made by the use of an artificial intelligence (AI) expert system. The selection may be based upon many factors for the particular farm including the soil type, crop rotation, type of tillage system, row spacings, and travel speed. The expert system develops a set of specifications for components to accomplish seven different planting functions and then matches those specifications with available machines. Soil erosion hazard is estimated, and the user is warned to use a more conservative tillage system if the estimate exceeds allowable limits.

INTRODUCTION
Conservation tillage technologies have evolved with continuous advancements in planters, drills, and seeders from the experimental machines of 20 years ago to an entourage of general and special purpose seeding machines. In 1986 there were an estimated 44 planters and 121 drills and air seeders available in the USA for conservation seeding (No-Till Farmer, 1986a, 1986b). Additionally, many add-on components are available from specialty companies, and total machines can be constructed with components from several sources. Considering all of the types of soil-engaging machine components from the suppliers, there may be as many as 1,200,000 possible combinations of components which could be selected for a seeding machine. In reality, several of the combinations might be adequate for a particular need, but there has not been a systematic process for developing specifications for a machine to perform a particular seeding operation (Erbach et al., 1983).

The best machine for a particular seeding operation and field condition has been determined by trial and error. Knowledge of these results may be too site-specific to advise farmers on current options, new technologies, and machine selection for other geographic areas, crops, or conditions. Huggins et al., (1986) stated that such up-to-date technology transfer can be available to the advisor and the farmer through the means of an "Expert System" (ES).

DESCRIPTION OF EXPERT SYSTEMS
An ES is an artificial intelligence (AI) computer system designed to simulate the problem-solving behavior of a human who is expert in a specialized area (domain) (Denning, 1986). The recommendations of the ES are based upon inputs from the user, outputs from external program algorithms, and results of if-then axioms and rules of inference derived from experts. The input process for the user is ideally simple and easy.
to use. The user establishes the local conditions and limitations of interest. External programs which contain established functional relationships, may be used to estimate values for properties or conditions that a human expert could use as the basis for making decisions and recommendations. Rules in an ES summarize the knowledge of highly-qualified individuals, known as "domain experts." The rules are structured as conditional if-then logical decisions and are known as the "knowledge base." Output from the application of the rules to the facts, by an "inference engine," constitutes a set of specifications or recommendations.

This report describes an ES for systematic recommendation of the best choice of soil-engaging components for conservation seeding machines. It is named 'PLANTING' and is intended to be used by advisors, distributors, and creditors for individual counseling with farmers as part of periodic evaluation of their crop production practices and machinery inventory management.

SOIL-ENGAGING COMPONENTS

Seeding machines can be characterized by their components which actively engage the soil. Those components are used to perform seven machine functions and have been identified by generic terminology, as given in Table 1. PLANTING seeks to identify appropriate soil-engaging components for the seven machine functions, based on the soil, residue, and climatic conditions of a specific location. The extent to which such conditional interactions are addressed by PLANTING depends upon the level of detail given by contributing domain experts.

The same soil-engaging components may be available as options on several different kinds of machines, such as row-planters, drills, and air seeders, and from several different manufacturers. In such cases, machines from several sources may provide comparable performance for the stated condition. In other cases, there may be few or no commercial machines available and custom modifications will be required to provide a seeding machine to meet the output specifications from PLANTING.

GENERAL STRUCTURE

PLANTING was developed by using the EXSYS2 (EXSYS Inc., Albuquerque, New Mexico, USA) shell for use on IBM PC2 compatible computers with MS DOS 2.02 or higher and a minimum of 256K of Random Access Memory (RAM). PLANTING is contained on one 5-1/4-inch3 size diskette for convenience with single-disk-drive computers. The output can be displayed on the computer screen, or may be printed for a convenient take-home copy for the user. Comparison of several sets of machine component specification outputs will provide the basis for decisions on not only the

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2Mention of a trademark or proprietary product does not constitute a guarantee or warranty of this product by the USDA and does not imply its approval to the exclusion of other products that may be suitable.

3'PLANTING' uses English units of measure for convenient communication with USA farmers.
appropriate conservation planting machines to use, but also the appropriate cropping practices for the field conditions.

SITE-SPECIFIC DATA BASE

PLANTING is provided with a soils data set for the particular location of the user. Soils selected from a master file may be specified for a county in a state, for all Major Land Resource Areas (MLRA) in a region, or by soil series name. The Rainfall and Runoff Factor (R) used in the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) to determine annual erosion is taken from charts prepared by Wischmeier (1976) and is included in the soil parameter file. The site-specific data base is copied onto a diskette along with the operational PLANTING files. This procedure is conducted at the USDA-ARS, Grassland, Soil and Water Research Laboratory, Temple, Texas, USA.

USER INTERFACE

Certain inputs are required to identify the user, establish the farming location, and describe cropping procedures. The user interface also includes user selection of options to review instructions for running EXSYS, view the knowledge base, view the rules as they are used, order reruns, and have a printout of the final report. An example of user inputs is given in Table 2.

EXTERNAL PROGRAM

PLANTING has an external program to process the selected soil and user-input data. The program uses the Pascal language and performs the following steps:

1) Explains the purpose of the expert system
2) Asks the user for personal information and writes it to the file which will contain the final output from the expert system
3) Displays a menu of soils with available parameters
4) Retrieves the parameters for the soil selected and writes them to a file in the format necessary for access by the expert system

KNOWLEDGE BASE

Domain experts contributed their knowledge to the formation of conditional if-then rules for an ES knowledge base. The knowledge base evolved as more and more experts contributed to PLANTING. Experts were free to make their rules dependent upon any crop, residue, or soil parameter as well as upon operational parameters.

The knowledge base is comprised of if-then rules in three functional groups: 1) rules for estimating annual soil erosion, 2) rules for selecting planting machine components, and 3) rules for matching available machines to the selected components.
INFEERENCE ENGINE

The EXSYS inference engine interrogates the if-then rules in PLANTING and performs the following functions:

a) Selects the appropriate residue factor for the previous crop residue
b) Calculates the amount of previous crop residue
c) Selects USLE C-factor by tillage input
d) Selects USLE P-factor by row orientation, slope, and slope length inputs
e) Selects USLE M-factor by row orientation, slope, and slope length inputs
f) Calculates the USLE maximum permissible C-factor
g) Calculates the USLE annual erosion soil loss
h) Compares annual erosion to allowable T-value from SCS soils data
i) Selects one or more components for each of the seven machine functions to produce a set of specifications
j) Matches machine component options to the set of specifications
k) Generates a report (Table 2)

The inference engine produces warnings to the ES user when the user inputs, soil, or crop conditions are incompatible. Warnings are contained in if-then rules in the knowledge base.

SUMMARY AND CONCLUSIONS

The expert system, PLANTING, has been designed and developed to systematically produce specifications for soil-engaging components on conservation planters, drills, and seeders. The specifications are matched to available seeding machines. Warnings are given to the user if intended cropping practices may produce excessive soil erosion, machine incompatibilities, and other irregularities. A final report is printed for the user.

Machine component selection will only be as good as the conditional rules from the domain experts. Verification trials are expected to yield additional expert rules. The soil data and user inputs seem to be sufficiently comprehensive to be non-limiting to the ES.

ACKNOWLEDGMENT

The expert system PLANTING was developed with the assistance of S. H. Parker, knowledge engineer, C. A. Jones, coordinator, and the following members of the American Society of Agricultural Engineers SW-225/1 Subcommittee: R. R. Allen, D. E. Wilkins, G. M. Powell, R. Grisso, D. C. Erbach, L. P. Herndon, D. L. Murray, G. E. Formanek, D. L. Pfost, M. M. Herron, and D. J. Baumert who contributed to the definition of soil-engaging components for each of the seven functional groups and served as domain experts for inference rule inputs.
LITERATURE CITED


Table 1. Planting machine components for each of seven machine functions.

<table>
<thead>
<tr>
<th>I. SOIL AND RESIDUE CUTTING</th>
<th>IV. SEED FIRMING</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Smooth coulter</td>
<td>1 Semi-pneumatic wheel</td>
</tr>
<tr>
<td>2 Notched coulter</td>
<td>2 Solid wheel</td>
</tr>
<tr>
<td>3 Coulter with depth bands</td>
<td>3 Not used</td>
</tr>
<tr>
<td>4 Bubble coulter</td>
<td>4 Provided by the rear unit</td>
</tr>
<tr>
<td>5 Rippled coulter</td>
<td></td>
</tr>
<tr>
<td>6 Narrow fluted coulter</td>
<td></td>
</tr>
<tr>
<td>7 Wide fluted coulter</td>
<td></td>
</tr>
<tr>
<td>8 Straw straightener</td>
<td></td>
</tr>
<tr>
<td>9 Powered blade or coulter</td>
<td></td>
</tr>
<tr>
<td>10 Strip rotary tiller</td>
<td></td>
</tr>
<tr>
<td>11 Dual secondary residue discs</td>
<td></td>
</tr>
<tr>
<td>12 Not used</td>
<td></td>
</tr>
<tr>
<td>13 Provided by the front unit</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>II. ROW PREPARATION</th>
<th>VI. SEED SLOT CLOSURE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Sweep row cleaner</td>
<td>1 Wide semi-pneumatic presswheel</td>
</tr>
<tr>
<td>2 Vertical discs row cleaner</td>
<td>2 Wide steel presswheel</td>
</tr>
<tr>
<td>3 Horizontal-disc row cleaner</td>
<td>3 Single-rib semi-pneumatic presswheel</td>
</tr>
<tr>
<td>4 Wide fluted coulter looseners</td>
<td>4 Double-rib semi-pneumatic presswheel</td>
</tr>
<tr>
<td>5 Chisel ripper</td>
<td>5 Narrow semi-pneumatic presswheel; &quot;V&quot;, rounded</td>
</tr>
<tr>
<td>6 Subsoiler ripper</td>
<td>6 Dual angled semi-pneumatic presswheels</td>
</tr>
<tr>
<td>7 Pack roller</td>
<td>7 Dual angled cast or steel presswheels</td>
</tr>
<tr>
<td>8 Basket roller</td>
<td>8 Narrow steel presswheel; &quot;V&quot;, rounded</td>
</tr>
<tr>
<td>9 Rotary cultivator</td>
<td>9 Split narrow presswheels</td>
</tr>
<tr>
<td>10 Spring tine cultivator</td>
<td></td>
</tr>
<tr>
<td>11 Not used</td>
<td>10 Dual wide presswheels</td>
</tr>
<tr>
<td>12 Provided by the front unit</td>
<td>11 Not used</td>
</tr>
<tr>
<td>13 S-tine cultivator</td>
<td>12 Provided by the rear unit</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>III. SOIL OPENING FOR SEED PLACEMENT</th>
<th>VII. DEPTH CONTROL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Double-disc opener</td>
<td>1 Rear presswheel</td>
</tr>
<tr>
<td>2 Staggered double-disc opener</td>
<td>2 Side guage wheel</td>
</tr>
<tr>
<td>3 Runner opener</td>
<td>3 Skid plate</td>
</tr>
<tr>
<td>4 Stub-runner opener</td>
<td>4 Frame lifting guage wheels</td>
</tr>
<tr>
<td>5 Hoe opener</td>
<td>5 Depth bands on front leading coulter</td>
</tr>
<tr>
<td>6 Single-disc opener</td>
<td></td>
</tr>
<tr>
<td>7 Coulter opener</td>
<td>6 Depth bands on disc opener</td>
</tr>
<tr>
<td>8 Chisel opener</td>
<td>7 Depth bands on disc opener</td>
</tr>
<tr>
<td>9 Wide-sweep opener</td>
<td>8 Down pressure only</td>
</tr>
<tr>
<td>10 Triple-disc opener</td>
<td>9 Provided by the rear unit</td>
</tr>
<tr>
<td>11 Powered blade or coulter opener</td>
<td></td>
</tr>
<tr>
<td>12 Provided by the rear unit</td>
<td></td>
</tr>
</tbody>
</table>
Table 2. Comparison of available machines for two different tillage inputs with example inputs.

1. Initial inputs:
   a) Name Joe and Jane Farmer
   b) Address Route 1
   c) Farm location: City-County-State Centerville-Henry County-Illinois
   d) Map page in County SCS Soil Survey Book, page no. 38
   e) Field location 60A
   f) Select a Soil Name, from menu Catlin

2. Input requested by the ES in the order of their occurrence:
   a) Select planters, drills or both Planters
   b) Select type of conservation tillage to be used, from menu Reduced and No-Tillage
   c) Select row orientation to slopes, from menu Contour
   d) Select crop name to be grown, from menu Corn
   e) Select wet or dry soil planting condition, from menu Dry
   f) Depth to impermeable soil layer 30 inches (76 cm)
   g) Row spacing 30 inches (76 cm)
   h) % Field slope 4.0%
   i) Slope length 80 feet (24 m)
   j) Minimum planting speed 4 mph (6.4 km/h)
   k) Select previous crop name, from menu Wheat
   l) Previous crop yield 50 bu/a (3360 kg/ha)

3. Example output (specification listing not shown):

<table>
<thead>
<tr>
<th>Available Machines</th>
<th>Reduced Tillage</th>
<th>No-Tillage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case I-H 800 (rear unit only)</td>
<td>Case I-H 800 (rear unit only)</td>
<td></td>
</tr>
<tr>
<td>Deutz-Allis 385</td>
<td>Deutz-Allis 385</td>
<td></td>
</tr>
<tr>
<td>Fleischer Buffalo-Slot, Buffalo-Till</td>
<td>Fleischer Buffalo-Slot</td>
<td></td>
</tr>
<tr>
<td>Hiniker 3500, 3600, 3800/Kinze</td>
<td>John Deere 7000, 7100, 7200</td>
<td></td>
</tr>
<tr>
<td>John Deere 7000, 7100, 7200</td>
<td>Kelley Series-16</td>
<td></td>
</tr>
<tr>
<td>Kelley Series-16</td>
<td>Kinze Single Frame, R'Fold, Twin Line</td>
<td></td>
</tr>
<tr>
<td>Kinze Single Frame, R'Fold, Twin Line</td>
<td>White 5100, 5700</td>
<td></td>
</tr>
<tr>
<td>White 5100, 5700</td>
<td>New Idea 900/Kinze, Double</td>
<td></td>
</tr>
<tr>
<td>Bush Hog Ro-Till (front unit only)</td>
<td>Acra V-Disc (rear unit only)</td>
<td></td>
</tr>
<tr>
<td>New Idea 900/Kinze Double</td>
<td>Yetter 6000 (rear unit only)</td>
<td></td>
</tr>
<tr>
<td>Acra V-Disc (rear unit only)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yetter 6000 (rear unit only)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cole 7500</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
EVALUATION OF TILLAGE AND EQUIPMENT TIMELINESS FOR SEMI-ARID OX-CULTIVATION

GICHUKI MUCHIRI

Ministry of Agriculture, Agricultural Engineering Division, P O Box 30028, Nairobi

ABSTRACT

Tillage and equipment performance factors are compared between furrow and flat-planting using bullock drawn Desi and conventional mouldboard plough respectively. The machine man hours per ha are used in a linear optimisation model where grain production is the objective function to be maximised subject to available land and weekly labour in timely and late planting of Katumani maize in semi-arid Eastern Kenya. The results show that it may be beneficial to delay planting part of the land in order to spread out weeding and optimise the use of available labour, land and bullock power.

INTRODUCTION

The benefits for timely crop planting in semi-arid areas are well known. These benefits may arise out of better utilisation of a combined effect of the solar radiation, soil moisture and nutrients whose individual effects cannot be easily isolated due to variability in semi-arid environment.

In large scale mechanised agriculture timely planting is achieved by a provision of large capacity equipment in what is called 'board' cultivation of Western North America and Australia. (FAO 1977) Minimum or zero tillage techniques are being applied to conserve soil, soil moisture and the attendant nutrients.

By contrast the historic small-scale semi-arid is dominated by animal drawn Babylonian Ard or Indian Desi plough in the Middle East, Indian Sub-continent, Sub Sahara Africa particularly in Ethiopia. Land preparation include several passes at a shallow (3-8cm) depth which keeps the weeds down and reduces surface evaporation (Russell 1961).

The rest of the small scale farming in semi-arid and semi-humid Middle and Southern Africa is dominated by animal drawn mouldboard (Victory)plough which was a part of the colonial technological package. The latter implement achieves equally shallow depth but demands greater draft for partial soil inversion and pulverisation. However, this shallow operation by either the Indian Desi plough or the African Victory plough does not produce sufficient micro-relief and soil depth to eliminate surface runoff and the attendant soil erosion on steep slopes currently being subjected to cultivation in relatively small (4-10ha) farms in semi-arid Africa. In fact it accelerates the formation of sub surface compact layer common in many semi-arid alfisols. Therefore there is a need to develop an alternative tillage technique which can reduce the formation of the sub surface compact layer to improve the soil water regime and root development. The area of data collection is located about 37.4 East and 1.5 South and has badly distributed bimodal rainfall of 500-700mm annually equally split between long rain (L.R.) March to June and short rains (S.R.) October to December.

This paper reports on the evaluation of an alternative tillage technique to enhance

- timely planting and weed control
- reduced labour and
reduced soil and moisture losses in terms of land and labour productivity using two bullocks in unusually slopping (5-15%) land in semi-arid Eastern Kenya.

MATERIALS AND METHODS

Controlled field tests compared two tillage and equipment systems namely:

i) mould ploughing including:
   dry and wet land ploughing and planting

ii) equipment innovation including:
   dry land chiselling and subsequent dry or wet land furrowing and planting.

Two men control the oxen and the implement while two more men follow and drop the seed and fertilizer and finally cover the seed. Fertilizer improved seed and chemical plant protection are omitted in low management treatment.

In absence of reasonable control on crop, soil and water relations, weeds and plant nutrients, results on crop yield were merely indicative and hence not proven. Effect of timeliness on crop yield was estimated from well controlled agronomic trials by Makatieni (1970, 1971).

In order to evaluate various timeliness schedules a linear programming (LP) model was formulated with production from cultivated land as the objective function as follows:- (Wagner, 1975, Muchiri, 1984)

\[
\text{maximise } Q = \sum_{n=0}^{3} \sum_{m=0}^{4} X_{nm} Y_{nm} \]

Subject to

\[
\sum_{n=0}^{3} \sum_{m=0}^{4} I_{nm} X_{nm} \leq L_i
\]

\[
\sum_{n=0}^{3} \sum_{m=0}^{4} X_{nm} \leq H
\]

\[
X_{nm} \geq 0
\]

Where

\(Q\) = Net production after deducting non-labour variable costs in material terms

\(n\) = number of weeks later in planting

\(m\) = number of weeks later in weeding

\(X_{nm}\) = plot of land in ha planted in weeks late and weeded \(m\) weeks late

\(Y_{nm}\) = expected yield from a crop planted \(n\) weeks late and weeded \(m\) weeks late

\(L_i\) = labour required per ha while performing an operation

\(I_{nm}\) = total labour available in week \(i\)

\(H\) = land available for cultivation in ha.

Of the 20 possible activities with each of the high and low management level of the recurrent non labour input (seed, fertilizer and chemicals) only 16 and 18 activities respectively which have a net return greater than zero are allowed in the model. Accordingly the LP matrix (table 2) shows the 34 decision variables with their coefficients expressed in kg of expected net yields of maize grain per ha dry matter.
The technical coefficients are expressed in labour requirements per ha while the constraints are the man hours for cultivation expected each week estimated from farm survey.

The farm operations are scheduled as follows:

- **Weeks 1**: 2 dry land chiselling
- **Weeks 3**: dry land preparation and planting
- **Weeks 4**: 5 wet land preparation and planting
- **Weeks 5**: 7 mechanical weeding by equipment innovation and supplementary hand weeding
- **Weeks 6**: 7 hand weeding of traditionally ploughed land
- **Weeks 8**: 14 hand weeding

Mechanical weeding by the traditional equipment is negligible because mouldboard plough may bury seedlings if early weeding is done.

**RESULTS**

Data reported here show that under very hard soil conditions of 5½ months drought preceding 1978 S.R., mouldboard plough failed to penetrate. Desi plough without chiselling penetrated to 9.0 cm deep, but required a very high draft averaging 183 kg. Subsequently it was shown that when preceded by chiselling the draft is reduced to about half.

Depth of tillage in combined chiselling and Desi furrowing was significantly greater than that achieved by the traditional mouldboard plough (table 1).

Labour and land productivity values derived from the Lp model show that equipment innovation if adopted may achieve more than double the current level (table 3). At 4.0 cultivated land the Lp output also indicate that an optimum family labour input per week is about 100 man hours equivalent to three adult labourers. At the same level of labour, of the 4.0 ha 2.70 may be planted dry while 0.24 ha may be planted wet compared to 1.0 and 0.8 ha respectively with the traditional equipment.

**Table 3 Labour productivity in kg. per adult**

<table>
<thead>
<tr>
<th>Available land in ha</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>1050*</td>
<td>1050</td>
<td>1050</td>
<td>1050</td>
</tr>
<tr>
<td>2100*</td>
<td>2300</td>
<td>2400</td>
<td>2400</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>930</td>
<td>930</td>
<td>930</td>
<td>930</td>
</tr>
<tr>
<td>1630</td>
<td>2130</td>
<td>2360</td>
<td>2470</td>
<td></td>
</tr>
<tr>
<td>110</td>
<td>775</td>
<td>775</td>
<td>755</td>
<td>775</td>
</tr>
<tr>
<td>1250</td>
<td>1775</td>
<td>2150</td>
<td>2375</td>
<td></td>
</tr>
</tbody>
</table>

* Upper figure is for old equipment
** Lower figure is for new equipment

Source: computed from farm net production generated by the Lp

For land/labour ratio of 1:1 land production is equal to labour productivity.
The results of this study are based in rough estimates of expected yields for early or late planted crop. The output is also influenced by fixing the work programme for the farmer which is unrealistic. These results are therefore useful for the purpose of comparing two technologies under assumed working conditions.

DISCUSSIONS AND CONCLUSION

It is quite clear that the significant improvement in the performance in terms of tillage parameters and labour is not meaningful until it is translated into realistic increase in productivity. The next stage of development is therefore to promote the training, extension and local production of the equipment innovation to achieve in this case the doubling of labour and land productivity.

This therefore is a methodology to evaluate the timeliness effect of tillage relative performance in terms of the land and labour productivity to give a justification for usually expensive training, extension and manufacturing programmes.

REFERENCES

F.A.O., 1971 Tillage and seeding practices and machines for crop production in semi-arid areas. FAO Rome.


TABLE 1

Performance Parameters for Equipment Innovation including Chisel and Desi Plough and A-Blade Weeder
All Mounted on Sine Hoe (1980 L.R.) and the Traditional Mouldboard Plough

<table>
<thead>
<tr>
<th>Implement/Operation</th>
<th>Depth cm.</th>
<th>Draft k.n.</th>
<th>Hours per ha</th>
<th>Manhours</th>
<th>Supplementary</th>
<th>Supplementary Manhours per ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chisel/Ploughing - dry</td>
<td>(11.5)</td>
<td>7.1</td>
<td>(59) 98</td>
<td>(11) 8.5</td>
<td>(22) 17</td>
<td>Seed &amp; Fertilizer</td>
</tr>
<tr>
<td>Subsequent Desi/Furrowing &amp; Planting - dry</td>
<td>(14)</td>
<td>12.4</td>
<td>(101) 102</td>
<td>(6) 7</td>
<td>(12) 14</td>
<td>Dropping &amp; Covering 27</td>
</tr>
<tr>
<td>Subsequent Desi/Furrowing &amp; Planting - wet</td>
<td>(15)</td>
<td>(106)</td>
<td>(6)</td>
<td>(12)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A-share/lst weeding</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6 12</td>
<td>Intra-row weeding 40</td>
</tr>
<tr>
<td>Desi plough winged/</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7 14</td>
<td>do</td>
</tr>
<tr>
<td>2nd weeding &amp; hillling</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Desi/furrowing - dry</td>
<td>9.3</td>
<td>183</td>
<td>8</td>
<td>16</td>
<td></td>
<td>Seed &amp; Fertilizer 27</td>
</tr>
<tr>
<td>Desi/furrowing - wet*</td>
<td>9.0</td>
<td>87</td>
<td>8.6</td>
<td>17</td>
<td></td>
<td>Dropping &amp; Covering 27</td>
</tr>
<tr>
<td>Mouldboard/ploughing - dry</td>
<td>8.5</td>
<td>101</td>
<td>12.5</td>
<td>25</td>
<td></td>
<td>do</td>
</tr>
<tr>
<td>Mouldboard/ploughing - wet*</td>
<td>8.4</td>
<td>9.4</td>
<td>19</td>
<td>25</td>
<td></td>
<td>do</td>
</tr>
<tr>
<td>Hand hoe/lst weeding</td>
<td></td>
<td></td>
<td></td>
<td>287</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hand hoe/2nd weeding</td>
<td></td>
<td></td>
<td></td>
<td>204</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Number in parenthesis refer to corresponding data for 1981 L.R.
The figures represent averages of fourteen plot observations.
Chisel ploughing was done under dry conditions.
Mouldboard ploughing was done under dry conditions.

* 1979 Data for short rains season
<table>
<thead>
<tr>
<th>WEEKS</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
<th>18</th>
<th>19</th>
<th>20</th>
<th>21</th>
<th>22</th>
<th>23</th>
<th>24</th>
<th>25</th>
<th>26</th>
<th>27</th>
<th>28</th>
<th>29</th>
<th>30</th>
<th>31</th>
<th>32</th>
<th>33</th>
<th>34</th>
</tr>
</thead>
</table>

**Note:**
1. The three level labour constraints namely 50, 80 & 110 manhrs/ha are entered parametrically.
2. Coefficients for decision variables for high & low management are 1-16 and 17-34 respectively expressed in kg net expected maize grain yield/ha dry matter.
3. Land constraint is varied parametrically between 1.5 to 6.0 hectares.
4. Underlined manhours per ha are for the corresponding operation with traditional equipment.
SOIL PROPERTIES UNDER BUSH, MANUAL CLEARING, PLOUGHING PLUS HARROWING AND RIDGING TREATMENTS AND EFFECT OF ROOT GROWTH AND YIELD OF MAIZE

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ABSTRACT

Soil physical properties, root growth and yield of maize under bush, manual clearing, disc ploughing plus harrowing and ridging treatments were investigated. Soil bulk density and temperature gradient increased in the order bush (BU), manual clearing (MC), ploughing plus harrowing (PH) and ridging (RG). Soil aggregate stability, water content and macroporosity decreased in the order BU, MC, PH and RG. Root growth decreased in the order MC, PH, and RG. Maize yield decreased in the order MC, PH and RG.

INTRODUCTION

Manual clearing of bush with cutlass, disc ploughing followed by disc harrowing and ridging are common methods of preparing soil for crop production in the tropics. However, no research information has been published on the relative extent to which these methods deteriorate soil productivity. This study reports assessments of soil texture, dispersion ratio, density, porosity, temperature, water status, maize root growth and yield pertaining to bush, manual clearing, ploughing plus harrowing and ridging.

METHODS

In October 1985, (a) secondary bush (Mainly herb Eupatorium Odoratum), (b) manual clearing, (c) disc ploughing plus disc harrowing and (d) ridging treatments, replicated 3 times, were performed at Akure (7°5'E, 5°10'E). In January 1986 surface soil samples collected over each plot were air-dried and sieved (2mm). The properties of samples collected thrice monthly were determined. Volumetric water content of sample put in oven at 100°C for 24h, and temperature gradient at 15,00h between 5 and 15 cm depths (using soil thermometer) were determined. Mechanical analysis was performed by hydrometer method. Dispersion ratio of soil in water as indicator of aggregate stability (Low, 1954) was evaluated as clay + silt in undispersed soil over %clay + silt after mechanical analysis. Bulk density of core samples was determined. Total porosity (St) was calculated from bulk density and particle density (2.65 g cm⁻³). Macroporosity (Sa) was obtained as Sa = St - Qv, where Qv is % water volume at 0.1 bar.

In March 1986 maize (Zea mays) was planted at 1 x 0.45m on soils that were cleared, ridged and ploughed - harrowed, and late crop was planted in July. Dry ear and grain yield at 14% (w/w) water content were obtained. Roots of 21 plants per treatment were extracted for the determination oven-dry (60°C) root weight and length 30 and 60 days after planting.

RESULTS

The soil under bush and manual clearing respectively had
higher aggregate stability than the soil that was ridged or
ploughed and harrowed (Table I). The latter treatments
respectively had higher dispersion ratio, sand and gravel
content. The soil under bush had the lowest bulk density in
more months and was followed by cleared soil. Ridging caused
the highest density in most of the months (Table II). The
mean values of bulk density follow the same trend as those of
dispersion ratio. The bush soil had the highest macroporosity
in most months (Table II) and was followed by the cleared
soil. Ridging produced the least macroporosity.

TABLE I

Soil physical properties in January 1986

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Sand (% w/w)</th>
<th>Silt</th>
<th>Clay (% w/w)</th>
<th>Gravel</th>
<th>Dispersion ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>BU</td>
<td>89.0</td>
<td>6.0</td>
<td>5.0</td>
<td>2.0</td>
<td>0.11</td>
</tr>
<tr>
<td>MC</td>
<td>91.4</td>
<td>5.5</td>
<td>3.1</td>
<td>1.3</td>
<td>0.30</td>
</tr>
<tr>
<td>PH</td>
<td>93.0</td>
<td>4.0</td>
<td>3.0</td>
<td>9.8</td>
<td>0.40</td>
</tr>
<tr>
<td>RG</td>
<td>94.3</td>
<td>2.7</td>
<td>3.0</td>
<td>25.5</td>
<td>0.61</td>
</tr>
<tr>
<td>LSD(0.05)</td>
<td>2.1</td>
<td>1.4</td>
<td>0.9</td>
<td>9.4</td>
<td>0.21</td>
</tr>
</tbody>
</table>

BU = Bush, MC = Manual Clearing, PH = Ploughing plus
Harrowing, RG = Ridging.

TABLE II

Bulk densities (g cm\(^{-3}\)) and macroporosities (%) of bush,
cleared and tilled soil in different months (1986)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>BU (g cm(^{-3}))</td>
<td>0.73</td>
<td>0.76</td>
<td>0.68</td>
<td>1.17</td>
<td>0.82</td>
<td>0.91</td>
<td>1.23</td>
<td>0.90</td>
</tr>
<tr>
<td>MC (g cm(^{-3}))</td>
<td>0.74</td>
<td>0.73</td>
<td>0.59</td>
<td>1.02</td>
<td>0.97</td>
<td>1.11</td>
<td>1.33</td>
<td>0.93</td>
</tr>
<tr>
<td>PH (g cm(^{-3}))</td>
<td>0.98</td>
<td>0.98</td>
<td>0.76</td>
<td>1.36</td>
<td>1.02</td>
<td>1.27</td>
<td>1.45</td>
<td>1.12</td>
</tr>
<tr>
<td>RG (g cm(^{-3}))</td>
<td>1.05</td>
<td>1.02</td>
<td>0.83</td>
<td>1.52</td>
<td>1.25</td>
<td>1.21</td>
<td>1.20</td>
<td>1.15</td>
</tr>
<tr>
<td>BU (%)</td>
<td>67.8</td>
<td>66.5</td>
<td>70.0</td>
<td>48.4</td>
<td>64.7</td>
<td>59.8</td>
<td>32.4</td>
<td>58.5</td>
</tr>
<tr>
<td>MC (%)</td>
<td>63.4</td>
<td>63.8</td>
<td>70.8</td>
<td>49.5</td>
<td>52.0</td>
<td>45.0</td>
<td>19.9</td>
<td>52.1</td>
</tr>
<tr>
<td>PH (%)</td>
<td>51.7</td>
<td>52.6</td>
<td>61.5</td>
<td>32.2</td>
<td>49.1</td>
<td>36.6</td>
<td>17.3</td>
<td>43.0</td>
</tr>
<tr>
<td>RG (%)</td>
<td>44.9</td>
<td>45.0</td>
<td>55.2</td>
<td>17.8</td>
<td>33.2</td>
<td>33.3</td>
<td>11.5</td>
<td>34.4</td>
</tr>
</tbody>
</table>

LSD (0.05) for mean density and macroporosity = 0.07 and 5.8
respectively.

Ridging and ploughing plus harrowing respectively produced
the least soil water content in more months (Table III). In
all months manually cleared soil had higher water content than
tilled soils. Ridging caused the highest soil temperature
gradient in more months (Table III) and was followed by
ploughing plus harrowing. In most months the soil under bush
and clearing treatments respectively had low temperature
gradient.

TABLE III

Water contents (%) v/v and temperature gradient (dT°C cm\(^{-1}\)) in
bush, cleared and tilled soil at different months.
**TABLE IV**

Mean root weight and length of a maize plant at different number of days after planting (dap).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Root Weight (g)</th>
<th>Maximum root length (cm)</th>
<th>Total root length (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>30 dap</td>
<td>60 dap</td>
<td>30 dap</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>60 dap</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>60 dap</td>
</tr>
<tr>
<td>BU (%) v/v</td>
<td>11.9 4.9 7.6</td>
<td>49.3 37.2 35.0</td>
<td>18.0 23.4</td>
</tr>
<tr>
<td>MC (%) v/v</td>
<td>7.8 1.8 13.0</td>
<td>39.8 25.1 23.3</td>
<td>21.2 18.9</td>
</tr>
<tr>
<td>PH (%) v/v</td>
<td>5.2 1.2 2.8</td>
<td>38.4 22.4 17.9</td>
<td>17.6 15.1</td>
</tr>
<tr>
<td>RG (%) v/v</td>
<td>6.4 0.7 3.5</td>
<td>35.0 14.4 11.5</td>
<td>16.8 12.6</td>
</tr>
<tr>
<td>BU (dT)</td>
<td>0.10 0.02 0.03</td>
<td>0.01 0.01 0.04</td>
<td>0.00 0.03</td>
</tr>
<tr>
<td>MC (dT)</td>
<td>0.12 0.04 0.08</td>
<td>0.03 0.04 0.04</td>
<td>0.11 0.07</td>
</tr>
<tr>
<td>PH (dT)</td>
<td>0.12 0.09 0.14</td>
<td>0.08 0.03 0.09</td>
<td>0.33 0.13</td>
</tr>
<tr>
<td>RG (dT)</td>
<td>0.13 0.05 0.10</td>
<td>0.12 0.04 0.10</td>
<td>0.58 0.16</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>0.7 4.1 2.2</td>
<td>4.1</td>
<td>28.1</td>
</tr>
</tbody>
</table>

**TABLE V**

Effect of tillage treatment on yield (tha⁻¹) of early (E) and late (L) maize

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Ear Yield</th>
<th>Grain Yield</th>
<th>Mean ear Yield</th>
<th>Mean grain Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>E</td>
<td>L</td>
<td>E</td>
<td>L</td>
</tr>
<tr>
<td>MC</td>
<td>13.3</td>
<td>11.9</td>
<td>6.6</td>
<td>7.7</td>
</tr>
<tr>
<td>PH</td>
<td>17.4</td>
<td>7.3</td>
<td>7.6</td>
<td>6.0</td>
</tr>
<tr>
<td>RG</td>
<td>10.6</td>
<td>5.9</td>
<td>4.6</td>
<td>4.8</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>3.4</td>
<td>3.5</td>
<td>2.7</td>
<td>2.7</td>
</tr>
</tbody>
</table>

DISCUSSION

The relatively high soil temperature gradient due to ridging and ploughing plus harrowing can be adduced to their lower water content. Thermal conductivity increases with soil water content for soils in Nigeria (Ghuman and Lal, 1985). Small root growth in ridged soil which had highest temperature gradient agrees with the fact that elongation of maize decrease...
with increase in maximum soil temperature (Maurya and Lal, 1981). Low maize yield due to ridging can be adduced to a combination of low soil water content (Ojeniyi, 1986) and high temperature.

CONCLUSIONS
(1) Removal of bush caused significant unfavourable change in soil macroporosity.
(2) In the short-term, ploughing plus harrowing is a close substitute for laborious manual clearing as maintenance of crop yield is concerned.
(3) Ridging is highly disadvantageous to soil physical properties and maize performance.

REFERENCES


ABSTRACT

The disc plough has been used by commercial farmers and the ox-drawn mouldboard plough by small-scale (peasant) farmers for over 60 years in Zimbabwe. However, the levels of water run-off and soil loss throughout the country have generally reached unacceptable proportions.

Changes in the attitudes of farmers to soil tillage are taking place, resulting in an increased acceptance of conservation tillage systems such as mulch farming and minimum tillage in the mechanised large-scale areas with tied ridging, and rip-and-plant techniques in the small-scale areas using ox draft. Is the plough on its way out?

TILLAGE USING OX DRAFT

History of Tillage and Trials

The use of the single furrow ox-drawn mouldboard plough by small-scale farmers was promoted through a major extension programme in the mid-1920's, whereas previously only a few very basic hand tools were used. Thus the ox-drawn mouldboard plough became the major primary tillage implement which is still the norm today. Indeed it was a major step forward promoting good weed control, nutrient and manure incorporation, a suitable seedbed and substantial soil rooting volume. In the 1950's local manufacture of ox-drawn ploughs and other equipment started, thus making the equipment readily available.

Soil tillage research started in the 1950's although most of the research has been directed at commercial farmers using tractor draft. The most significant work affecting both peasant and commercial farmer was that of the depth of ploughing trials (Grant et al, 1979) from which came the general recommendation for ploughing to be between 200 and 250 mm deep. (Summarised in Fig. 1.) These results were confirmed in large-scale layout trials.
Fig. 1. YIELD EFFECTS OF PLOUGHING DEPTH

Smith (1981) summarises the findings of tillage research using ox draft. Mulches on sandveld had little effect on maize yield. Frequency of tillage trials have shown that yields during reduced or zero tillage phases of a rotation are lower than those under continuous plough, but higher in the plough year giving equable results to continuous ploughing on average. Maize could be established successfully after ripping with a tine but yields were slightly lower than for the plough.

Conservation tillage trials conducted under semi-arid conditions have shown microcatchment tillage (or furrow planting as it is sometimes known) to have great potential particularly on the heavier soils (Nyamudeza, 1987). Countrywide observation tillage trials have shown the communal farmers are able to cope with rip-on-row and tied ridging tillage and on average get the same yields as ploughing (Norton, 1987a).

Current Situation: Problems and Practices

Other than the major extension drives to encourage ploughing in the 1920’s and the use of the ripper tine in 1977/78, most tillage recommendations are extended through routine in-service training courses. Yet despite some considerable research effort over the past 30 years and considerable success with tillage which conserves soil, moisture, time and energy (Norton, 1987a) farmers still adhere to traditional and often not very effective practices. Ploughing is still used extensively on an estimated 73 - 90 percent of cultivated land with less than 1 percent using reduced and conservation tillage (Froude et al, 1988). The standard of ploughing is poor with depths being typically half the recommended 200 - 250 mm.
There are several contributory factors to this situation. Frequently new concepts are put forward on a purely technical basis with no consideration for economics or social implications. The farmer is often unable to control weeds under the new system. Instruction can be lacking and success is dependent upon the drive of the extension worker. Suitable machinery is often unavailable and this fact combined with poor weed control partly explains the poor adoption of the ox-drawn ripper (Smith, 1981). Tradition and the "safety" of a well-known system also plays a large part. Perhaps the greatest problem constraining small-scale production is the inability to achieve timely planting, due to untimely land preparation which is mainly as a result of poor availability of draft. Weed control is critical, especially couch grass (cynodon dactylon) on the granitic sands, and the reason ploughing - sometimes twice between seasons, is preferred.

Future directions

Despite the current problems facing farmers and the poor adoption of better practices, the research evidence for the viability of these improved practices is documented and with the right extension approach, there should be a substantial improvement in their adoption. The associated machinery is steadily being designed/improved and made available commercially. A new series of conservation tillage trials is being initiated to make understood more fully the principles involved and be able to extend them to other soil and climatic environments. The recent introduction of granular herbicides may result in more economic weed control in reduced forms of tillage.

The Institute of Agricultural Engineering is strongly promoting the use of semi-permanent tied-ridges (Norton, 1987a,b) in an attempt to promote moisture, time and energy conservation, and reduce the excessive (estimated) soil losses of 50 t/ha/year (Elwell, 1983). The system requires a ridger for installation and maintenance, although construction by hand and the plough is equally effective. There is no doubt that good quality full depth ploughing carried out in autumn so as to facilitate early planting, is an effective and well understood way to achieve acceptable crop yields. However, tied ridging is preferred and it is expected that ploughing will become less important as time goes by.

TILLAGE USING TRACTOR DRAFT

From the early 1900's to 1970 the bulk of commercial farming land was ploughed, using tractor mounted, or drawn, disc ploughs. Until the 1950's these ploughs were imported, thereafter the manufacture of locally designed, fixed beam disc ploughs began and proved to be a major breakthrough, as these ploughs were more robust than the imported models and suited the hard, dry winter ploughing conditions. A further major breakthrough was made later in the 1970's when reversible disc ploughs were manufactured locally. In their hayday three different makes of reversible plough were
available in models varying from two disc mounted to six disc semi-mounted, all locally designed. The reversible plough took over the market to the extent that since the 1970's very few fixed beam ploughs have been sold and the National Ploughing Association of Zimbabwe adopted the reversible disc in place of the fixed beam disc as one of its two competition classes.

Results of tillage research trials during the 1970's (Meikle, 1974) showed significant savings in time and expense from using the rip-and-disc technique, and the swing away from widespread use of the plough began.

The technique of rip-and-disc is still very common today - so much so that it can be regarded as the 'conventional' land preparation method. A few farmers still use a plough for all their primary tillage work, some use the plough in rotation (one year in two or three) with rip-and-disc, but there are more and more who do not now own a plough.

Variations on the rip-and-disc method include: initial discing followed by crop establishment and then an inter-row-rip after crop emergence, a large number of growers use only the disc harrow and a periodic rip or plough. These methods while quicker and cheaper than ploughing (21 litres of fuel/ha versus 31 litres/ha.) have proved a mixed blessing in that the continuous use of the disc seems to be having a serious detrimental effect on soil structure (Elwell, 1984); run-off and soil loss from bare soils is unacceptably high (commonly 80 t/ha/yr.) (Meikle, 1982).

The second swing to minimum till and zero till techniques has started, not necessarily for reasons of soil conservation, but techniques such as rip-on-row and direct planting into stubble are proving so much less expensive, in spite of increased herbicide costs in the first years. The improved water infiltration and decreased soil loss with these methods are highly significant and while yields may be no better than those under conventional treatments and even ploughing treatments, the financial viability is encouraging. The theory that the less the soil is worked the easier it becomes to work, seems to be proving correct in many, though not all, cases.

One limitation to more widespread adoption of minimum and zero till techniques is the lack of suitable equipment designed to work through, rather than incorporate, crop residues, although in several cases the farmers' ingenuity has overcome the problem. Local commercial development of zero till attachments to row crop planters is well advanced and a limited production is taking place in readiness for the coming October/November planting season.

Chisel ploughing is replacing the disc harrow on many farms, field measurements having shown the vastly reduced soil loss and run-off quantities from tined soil as opposed to disced soil (Elwell, 1984) as a direct result of less destruction to water stable aggregates. However, the main effort is towards
those techniques which "... retain at least 30 percent of crop residue cover on the soil surface after the planting operation." (an accepted definition for "conservation tillage").

In spite of the enormous benefits, practical problems encountered in retaining residues on the surface cannot be underestimated, they are being studied by researchers, farmers and chemical company representatives on an increasing scale. No known tillage system which leaves a bare soil at planting time, be it ploughed, chiselled, disced or ripped, has shown soil loss figures approaching those from the conservation till methods, measured at less than two tonnes per hectare on some trials. (Elwell, 1988).

The replicated trial on ART Farm of summer soya/winter wheat, comparing zero till with conventional till is now in its fourth summer crop. Results to hand after the third crop are showing a trend towards higher yields in the zero till plots and more profitable return than the conventionally tilled plots.

Field scale comparisons of conservation till and conventional till on adjacent fields on ART Farm showed that in spite of a yield reduction of 18 percent on the conservation tillage land there was a time saving of 60 percent, fuel saving of 64 percent on land preparation; a saving of 34 percent in total variable costs and an increased gross margin of 67 percent.

These comparative results are borne out by those on several commercial farms around the country and are showing, in addition, that benefits of the crop residue surface cover are felt both in dry and wet years.

Add to these economic and production benefits the reduction in soil loss and water run-off under conservation tillage and there remain very few real reasons to use the plough at all.

Constraints to a more rapid and widespread adoption of conservation till methods are: lack of specialised machinery for working through residues and the belief that a much higher level of management is required for successful conservation tillage.

CONCLUSIONS

1. There is a definite move away from ploughing and discing towards chiselling and zero tilling in Zimbabwe's commercial farming areas.

2. Conservation tillage practices leaving adequate surface mulching are the best known means of containing soil loss and water runoff within acceptable proportions in Zimbabwe.
3. The conservation tillage methods discussed are highly cost effective given an adequate level of management.

4. The research, development and extension effort must concentrate on furthering conservation tillage practices in preference to existing traditional practices in all areas of Zimbabwe.

REFERENCES


EFFECT OF SUBSOILING A COMPACTED CLAY LOAM SOIL ON THE NITROGEN UPTAKE OF WHEAT.

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ABSTRACT

Subsurface compaction is a serious problem in most irrigated soils of Morocco. Field studies were conducted in 1983 and 1987. A single-tooth subsoiler was pulled through the soil at 0.4m intervals, to a depth of 0.7m. Soil mechanical resistance of the entire subsoiled plots was decreased by 25 to 44% at the 0.20-to 0.45-m depth. At this same depth, roots were 26 to 46% longer per unit weight. Throughout the growing seasons, plants grown on subsoiled plots were consistently and significantly taller and tended to accumulate more dry matter (33 to 53%), and more nitrogen per shoot especially at anthesis (10 to 32%). Similarly, there was more biomass produced per unit area on subsoiled plots. The result was a significant increase in the total amount of N being extracted per unit area from subsoiled plots (28 to 46%). Since the N concentration in individual shoots was unaffected by subsoiling, this increased N uptake which was attributed to the increase in biomass, and not to any difference in N uptake ability, or in inherent root efficiency as a result of subsoiling.

INTRODUCTION

The recent use of heavy machinery combined with the frequent use of the disc implement for soil tillage under intensive cropping systems has led to the creation of subsurface compacted horizons in many of the irrigated soils of Morocco. Recent studies have shown that subsoiling has effectively alleviated to the extent that the growth of wheat (triticum aestirum, L.) was improved (Oussible and Crookston, 1987). Subsoiling studies in other countries have provided mixed results. Ericksson et al., (1974); Allmaras (personal communication) have reported no consistent beneficial effect resulting from deep loosening. However, other scientists such as Patrick et al., (1959); McEwen and Johnston (1979) and others, have obtained improved growth and yield of several crops following subsoiling. Few of these studies have attempted to explain the nature of the positive crop growth response to deep plowing. Oussible and Crookston (1987) attributed the increase in grain yield to the increase in yield components: spike number, kernels per spike and kernel weight. The objective of this study was to determine whether the improved growth and yield of wheat was associated with any effect on nitrogen uptake of wheat under field conditions.
MATERIALS AND METHODS

Two field experiments of 1-yr. duration each were conducted in 1983 and 1987 at the Tadla experiment station of the Hassan II Institute of Agronomy and Veterinary Medicine. The soil is a well-drained clay loam (Typic Calcixeralf) consisting of 22% sand, 39% silt, 37% clay, and 2% organic matter, with a pH of 7.2. The wheat cultivar "Nesma 149" was grown both years at a seeding rate of 125 Kg/ha. The preceding crop was soybeans (Glycine max L. Merr) to the 1983 trial, and was alfalfa (Medicago sativa L.) to the 1987 trial. Soil tests indicated that P and K were satisfactory for wheat production and no fertilizer (including N) was applied. Plots which consisted of 15 rows each 15m long and spaced 0.20 apart, were arranged in a randomized complete block with four replications. Subsoiling was accomplished by means of a single-tooth subsoiler that was pulled through the soil at 0.4-m intervals to a depth of 0.7m. Soil moisture at the time of subsoiling was adequate for good soil shattering.

The affect of subsoiling on the soil mechanical resistance was measured with a hand-held proving ring penetrometer with a 30° angle cone having a 10.5-mm base diameter. Readings were taken during anthesis at 50mm increments and to a depth of 0.45m.

Root growth was characterized via soil samples collected at anthesis at different depths of the soil profile: 0 to 0.15m, 0.15m to 0.25m, 0.25 to 0.35m, 0.35 to 0.45m and 0.45m to 0.60m. This was done by pushing a steel cylinder (45mm in diameter and 57mm long) horizontally into the wall of a pit that was dug in the center of each plot. Roots were separated from the soil by gentle washing, and length was measured according to the technique of Voorhees et al., (1980). Once the root length was determined, roots were oven-dried for 36h at 60°C for dry weight determination. Root fineness was also estimated by computing root length/weight ratio.

Shoot growth was quantified both years via seasonal measurements of plant population, plant height, and dry matter. Seedling and plant population were measured on one square meter per plot. Plant height was measured on fifteen labelled plants per plot. Dry matter per shoot and individual organs were determined by harvesting fifteen equally-developed shoots from each plot at different growth stages: tillering, boot, anthesis, and maturity. These shoots were washed, cleaned, and separated into leaves, stems, chaff and kernels, and oven-dried for 36 hours at 60°C. At maturity, spike number, and grain and straw yields were determined on each of five square meters within each plot. Yield components were measured on fifteen randomly-harvested spikes from each of the five square meters.

Nitrogen uptake was determined via sequential measurements of N concentration and N content of whole shoot and individual organs on the same plant samples used for dry matter at tillering, anthesis, and maturity. After dry matter was measured, plant samples were ground and N concentration was determined using the standard Kjeldahl method. N content was
computed by multiplying N concentration by the corresponding dry matter. At maturity, the total amount of N accumulated per unit surface area in the grain, straw and total aerial biomass was determined on each of the five individual square meters per plot used for grain and straw yield determination.

RESULTS AND DISCUSSION

Soil strength.

The subsoiling had a striking effect on the soil mechanical resistance. There was nonetheless a significant decrease in the average mechanical resistance of the entire subsoiled plots. This consisted of a decrease of 25 to 33% at the 0.25-to 0.35-m depth in 1983, and a decrease of 36 to 44% at 0.15-to 0.45-m depth in 1987 (data not presented). Similar results were reported by Oussible and Crookston (1987).

Plant growth and yield.

The observed changes in the mechanical status of the subsoiled profile directly affected several root growth characteristics. First, root elongation was increased by 13 to 16% at the 0.25-to 0.35-m depth in 1983, and by a significant increase of 24% at the 0.30-to 0.50-m depth in 1987. Second, there was an important change in the root morphology and distribution within the 0.20-to 0.60-m depth, where roots from subsoiled plots tended to proliferate by more branching and the production of more fine roots. The roots growing in this loose zone were 26 to 46% longer per unit weight than those at the same depth of the check plots.

Table 1. Total dry matter per shoot and its distribution among individual organs of wheat as affected by subsoiling (Tadla, Morocco, 1983).+  

<table>
<thead>
<tr>
<th>growth stage</th>
<th>sample</th>
<th>subsoiled</th>
<th>control</th>
<th>LSD_{0.05}</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mg/shoot</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tillering</td>
<td>whole shoot</td>
<td>72</td>
<td>74</td>
<td>ns*</td>
</tr>
<tr>
<td>Boot</td>
<td>whole shoot</td>
<td>380</td>
<td>278</td>
<td>87</td>
</tr>
<tr>
<td></td>
<td>leaves</td>
<td>179</td>
<td>143</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td>stem</td>
<td>202</td>
<td>134</td>
<td>47</td>
</tr>
<tr>
<td>Anthesis</td>
<td>whole shoot</td>
<td>1792</td>
<td>1172</td>
<td>298</td>
</tr>
<tr>
<td></td>
<td>leaves</td>
<td>391</td>
<td>294</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>stem</td>
<td>1031</td>
<td>627</td>
<td>231</td>
</tr>
<tr>
<td></td>
<td>head</td>
<td>379</td>
<td>252</td>
<td>78</td>
</tr>
<tr>
<td>Maturity</td>
<td>whole shoot</td>
<td>3794</td>
<td>2726</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td>leaves</td>
<td>376</td>
<td>260</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td>stem</td>
<td>1208</td>
<td>897</td>
<td>183</td>
</tr>
<tr>
<td></td>
<td>chaff</td>
<td>492</td>
<td>435</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td>kernels</td>
<td>1200</td>
<td>1115</td>
<td>ns</td>
</tr>
</tbody>
</table>

+Only 1983 data are presented. Similar trends were observed in 1987.  
* nonsignificant
Subsoiling had no effect on plant population at any of the sampling dates. However, plants grown on subsoiled plots were significantly taller at most measured growth stages, and tended to accumulate more dry matter per shoot (33 to 53%) than those grown on check plots especially during vegetative growth (table 1).

Subsoiling resulted in a significant increase of 30 and 33% in grain yield, and 17 and 31% in straw yield in 1983 and 1987 respectively (table 2). All measured yield components contributed to the increase in grain yield. Spike number, kernels per spike, and kernel weight were increased by 7, 19 and 11%, and 16, 12 and 4% in 1983 and 1987, respectively, (data not shown).

Table 2. Wheat grain and straw yields as affected by subsoiling (Tadla, Morocco, 1983 and 1987).

<table>
<thead>
<tr>
<th></th>
<th>1983 grain yield (kg/ha)</th>
<th>1983 straw yield (kg/ha)</th>
<th>1987 grain yield (kg/ha)</th>
<th>1987 straw yield (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>subsoiled</td>
<td>3255</td>
<td>5553</td>
<td>3215</td>
<td>6429</td>
</tr>
<tr>
<td>control</td>
<td>2457</td>
<td>4231</td>
<td>2479</td>
<td>5515</td>
</tr>
<tr>
<td>LSD0.05</td>
<td>433</td>
<td>960</td>
<td>708</td>
<td>ns</td>
</tr>
</tbody>
</table>

Nitrogen uptake.

Subsoiling had no significant effect (P<0.05) on N concentration on a per shoot or any individual organ basis on most sampling dates over the 2 years (table 3). This suggested that wheat roots grown in subsoiled and check plots did not differ in their ability to take up N even though subsoiling improved root growth conditions.

Table 3. Effect of subsoiling on the nitrogen concentration in the whole shoot and individual organs of wheat (Tadla, Morocco, 1983).*

<table>
<thead>
<tr>
<th>Growth stage</th>
<th>sample</th>
<th>subsoiled</th>
<th>control</th>
<th>LSD0.05</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-------</td>
<td>-----------</td>
<td>---------</td>
<td>---------</td>
</tr>
<tr>
<td>Tillering</td>
<td>whole shoot</td>
<td>3.75</td>
<td>3.34</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td>whole shoot</td>
<td>1.73</td>
<td>2.01</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td>leaves</td>
<td>2.12</td>
<td>2.02</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td>stem</td>
<td>1.53</td>
<td>2.00</td>
<td>0.47</td>
</tr>
<tr>
<td></td>
<td>head</td>
<td>1.06</td>
<td>2.19</td>
<td>ns</td>
</tr>
<tr>
<td>Anthesis</td>
<td>whole shoot</td>
<td>1.66</td>
<td>1.58</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td>leaves</td>
<td>1.34</td>
<td>1.32</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td>stem</td>
<td>0.67</td>
<td>0.67</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td>chaff</td>
<td>1.01</td>
<td>0.89</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td>kernels</td>
<td>2.95</td>
<td>2.71</td>
<td>ns</td>
</tr>
</tbody>
</table>

*Only 1983 data are presented. No significant effect was observed in 1987.
Similarly, N accumulated in the whole shoot and in individual organs was not significantly changed by subsoiling on 2 out of 3 sampling dates. However, the trends toward higher values in subsoiled plots were consistent especially at anthesis where significant differences were recorded mainly in 1983 (data not shown). This observed trend in N accumulation follows the same pattern as that of dry matter accumulation.

On a per-hectare basis however, subsoiling resulted in 44% increase in N accumulated in the grain, and 28% in the straw in 1983. In 1987, deep loosening increased N accumulated in the grain by 32% and in the straw by 20%. Total N uptake in the aerial plant biomass on a per-unit area basis was increased by 46% in 1983 and 28% in 1987 (table 4). Nitrogen harvest index however, was not affected by deep tillage. This indicated that N partitioning into the grain was unaffected by subsoiling.

Table 4. Effect of subsoiling on the nitrogen accumulated in the grain, straw and aerial biomass of wheat (Tadla, Morocco, 1983 and 1987).

<table>
<thead>
<tr>
<th>growing season</th>
<th>treatments</th>
<th>N accumulated in the</th>
<th>N harvest index</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>grain</td>
<td>straw</td>
</tr>
<tr>
<td>1983</td>
<td>subsoiled</td>
<td>96</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>control</td>
<td>67</td>
<td>34</td>
</tr>
<tr>
<td></td>
<td>LSD0.05</td>
<td>15</td>
<td>11</td>
</tr>
<tr>
<td>1987</td>
<td>subsoiled</td>
<td>69</td>
<td>41</td>
</tr>
<tr>
<td></td>
<td>control</td>
<td>52</td>
<td>34</td>
</tr>
<tr>
<td></td>
<td>LSD0.05</td>
<td>15</td>
<td>6</td>
</tr>
</tbody>
</table>

As was shown earlier, plants grown on subsoiled plots were taller and tended to accumulate more dry matter and more nitrogen per shoot. Also, at maturity, the increase in all measured yield components has led to the production of more biomass per unit area on subsoiled plots than on check plots. The overall result was a significant increase in the total amount of N being extracted per unit area from subsoiled plots. Since the N concentration in individual shoot was unaffected by deep tillage, the increased N uptake was attributed to the increase in biomass, and not to any difference in N uptake ability, or in inherent root efficiency as a result of subsoiling. Similar results were reported by McEwen and Johnston (1979) who attributed the increase in N uptake in the grain of wheat and barley to the difference in grain yield.

CONCLUSION

1 - Wheat root ability to take up nitrogen was similar in subsoiled and check plots even though subsoiling improved root growth conditions.

2 - At harvest, total nitrogen uptake in the grain and straw was markedly increased by subsoiling.
3 - The increased nitrogen uptake at maturity was attributed to the increase in biomass.

REFERENCES

THE INFLUENCE OF TILLAGE METHODS ON SOIL-WATER CONSERVATION IN SW SPAIN

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²Instituto de Recursos Naturales y Agrobiologia (CSIC), (P.O. Box 1052, 41080 Seville, Spain).
³Escuela Técnica Superior Ingenieros Agronomos, Universidad de Madrid (Ciudad Universitaria, Madrid, Spain).

ABSTRACT

In the present work the effect of several tillage methods on the physical properties of a sandy clay loam (Haploxeralf) from Seville province (SW Spain) has been studied in order to establish the optimum management for water intake and conservation in the soil.

The tillage methods considered have been the following: disc ploughing, mouldboard ploughing, cultivator application, disc-harrowing and no-tillage. Two crops have been used: wheat and sunflower. In each treatment systematic measurements of bulk density, hydraulic conductivity and infiltration rate in the top layer have been carried out. Changes in water profiles through the experimental period have also been followed.

Results presented in this paper correspond to the period autumn 1986–June 1987. They show up important differences in soil physical properties as well as in the rate of replenishment and depletion of soil water storage due to treatments. Disc-harrowing seems to be best for water conservation. Differences in crop response have also been observed.

INTRODUCTION

Relationships between soil tillage methods and soil physical properties and consequently crop response have since very long been observed. Soil water storage and conservation depend largely on conditions present in the arable layer due to the particular tillage method used. In soils of the Andalusian plain (SW Spain), climatological conditions, characterized by the concentration of rainfall in the period autumn–winter, lead to replenishment of water storage capacity at the end of winter, the shortage of precipitation afterwards, together with very high temperatures being responsible for the water depletion observed at the end of summer. These facts are particularly important in dry land farming in this zone, where water availability is the most important limiting factor (Moreno et al., 1981).

Some work has been carried out in the last few years to determine the most appropriate tillage methods to achieve an op-
timun replenishment and conservation of water in the profile of soils of western Andalusia for a convenient development of dry farming crops (particularly cereals). It should be cited, amongst others, works by Garcia et al. (1986), Moreno et al. (1982, 1986), Pelegrin et al. (1987), in which the above-mentioned relationships are clearly shown for soils of different texture found in the region.

In the present paper different soil physical properties are studied in relation to the effect due to the various tillage methods used to determine the amount of water availability in the profile and its effect on the growth of wheat and sunflower.

MATERIAL AND METHODS

Field experiments have been developed on a 1-ha plot, divided into 28 x 3 m subplots, situated within the experimental area of the University School of Agricultural Technical Engineering (EUITA/CEI) 3 km East of Seville city. The soil is considered as Haploxeralf, its textural and mechanical characteristics being shown in Table I.

The following tillage treatments have been used: disc ploughing, mouldboard ploughing, cultivator application, disc harrowing and no-tillage, with three replications per treatments. In the present work changes in soil water profiles during the period autumn 1986 to June 1987 are shown for wheat and sunflower (single hybrid) crops.

The following measurements have been carried out:

a) In situ
- infiltration by double-ring infiltrometre (Bouwer, 1961).
- water profiles changes by neutron probe (Troxler 3333).

b) In the laboratory
- hydraulic conductivity in saturated conditions according to Flannery and Kirkham (1964) by a permeameter developed by Martin-Aranda (1973).
- bulk density, from the ratio mass/volume of soil cores taken with stainless steel cylinders 8 cm diameter and 4 cm height.
- particle size distribution by chain hydrometre (De Leenheer et al., 1965).
- moisture retention characteristic curves by suction in fritted-glas plates (Vomocil, 1965) and by pressure in ceramic plates (Richards, 1948).

RESULTS AND DISCUSSION

Texture of the soil, in the upper 40 cm of the profile, corresponds to a sandy clay loam, the amount of clay increasing with depth. This pattern is uniform in all the plot (Table I). Values of bulk density and hydraulic conductivity for given dates during experimental period are shown in Table II. These results show an increase of bulk density in the arable layer with time, being more noticeable in cultivator and no-tillage treatments. A considerable reduction of hydraulic conductivity
in that layer is also observed in all treatments.

Infiltration rates have been measured in two moments: the first immediately after tillage operations and the second at the end of spring (6 months after autumn tillage operations). Results can be observed in graphs of Fig. la and lb. They clearly show up that infiltration rates are different in each treatment, in the first moment (Fig. la), a constant value being reached after 90 minutes. This value is the same for disc and mouldboard ploughing. Cultivator and disc harrow treatments also show similar although lower values than in previous case. No-tillage treatment shows the lowest value.

Results in Fig. lb shows that, after rainfall period and crop development (second moment) infiltration rates diminish drastically, due to drying and sealing of the soil surface as well as to natural compaction. All treatments show different values except disc harrowing and no-tillage which are similar.

Soil water storage replenishment and evolution, for wheat crop, in each treatment, are given in graphs of Fig. 2a. These results show that in December 1986, few days before emergence water storage is not yet refilled, important differences being observed between treatments, in agreement with the different rates of infiltration observed. Replenishment of deep layers in the soil profile take place in January-February (1987) reaching ca field capacity. By middle of March (plant height 50 cm) water extraction by the crop is noticeable down to 60 cm depth, in all treatments, being more distinct in the mouldboard ploughing case, and the lower extraction in the disc harrowing one, probably due to differences in root distribution and depth, as a consequence of the various tillage methods applied. By June (full crop), profile sequence is the same, although a clear

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Soil particle size (% w/w; μm)</th>
<th>Dp (g/cm³)</th>
<th>L.L.</th>
<th>P.I.</th>
<th>P.I.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-20</td>
<td>22.1 42.7 8.5 27.7</td>
<td>2.70</td>
<td>26.0</td>
<td>12.7</td>
<td>13.3</td>
</tr>
<tr>
<td>20-40</td>
<td>23.4 40.5 7.5 28.0</td>
<td>2.72</td>
<td>26.8</td>
<td>13.5</td>
<td>13.3</td>
</tr>
<tr>
<td>40-60</td>
<td>27.5 32.0 7.5 32.5</td>
<td>2.72</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>60-80</td>
<td>25.5 31.5 5.0 37.5</td>
<td>2.73</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>80-120</td>
<td>18.0 27.0 14.5 39.5</td>
<td>2.75</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Dp: particle density; L.L.: Liquid limit; P.I.: Plastic limit; P.I.: Plasticity index

Table II. Dry bulk density (Db) and saturated hydraulic conductivity (Ks) during the experimental period in the top layer (0-20 cm)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>November 1986</th>
<th>June 1987</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Db (g/cm³)</td>
<td>Ks (mm/h)</td>
</tr>
<tr>
<td>Disc-ploughs</td>
<td>1.22</td>
<td>91.5</td>
</tr>
<tr>
<td>Mouldboard-ploughs</td>
<td>1.25</td>
<td>45.5</td>
</tr>
<tr>
<td>Cultivator</td>
<td>1.24</td>
<td>43.5</td>
</tr>
<tr>
<td>Disc-harrow</td>
<td>1.34</td>
<td>50.3</td>
</tr>
<tr>
<td>No-tillage</td>
<td>1.51</td>
<td>11.0</td>
</tr>
</tbody>
</table>

Results in Fig. lb shows that, after rainfall period and crop development (second moment) infiltration rates diminish drastically, due to drying and sealing of the soil surface as well as to natural compaction. All treatments show different values except disc harrowing and no-tillage which are similar.

Soil water storage replenishment and evolution, for wheat crop, in each treatment, are given in graphs of Fig. 2a. These results show that in December 1986, few days before emergence water storage is not yet refilled, important differences being observed between treatments, in agreement with the different rates of infiltration observed. Replenishment of deep layers in the soil profile take place in January-February (1987) reaching ca field capacity. By middle of March (plant height 50 cm) water extraction by the crop is noticeable down to 60 cm depth, in all treatments, being more distinct in the mouldboard ploughing case, and the lower extraction in the disc harrowing one, probably due to differences in root distribution and depth, as a consequence of the various tillage methods applied. By June (full crop), profile sequence is the same, although a clear
Fig. 1. - Evolution of the infiltration rate in the different treatments, in two dates during experimental periods.

Fig. 2. - Changes of water profiles in the different treatments: (a) during wheat growth and (b) during sunflower growth.
difference is observed for the depth at which water content is equal or below wilting percentage: 30 cm in disc-harrowing case and 60 cm in mouldboard ploughing; the other treatments show an intermediate sequence.

In the case of sunflower (Fig. 2b), in which the initial water status in the profile is very similar in all treatments (except in no-tillage, where water content is lower in the first meter depth), differences are also found in water profiles due to extraction by crop.

The cultivator treatment shows the larger extraction to a meter depth and, as in the case of wheat, disc-harrowing treatment is the best for water conservation, even at the time the plants have already completed their buds (Fig. 2b). Afterwards water depletion reaches deeper layers. Considering the evolution observed at 150 cm depth, water extraction should take place below that level as it has been shown by Unger et al. (1976) and, in our region, by Berengena et al. (1985).

In both crops used, the differences in water status in the soil, as a consequence of the different tillage methods applied affect production, scarcely in wheat and noticeably in sunflower.

CONCLUSIONS

From results shown it can be deduced that soil physical properties (bulk density, hydraulic conductivity and infiltration rate) are different due to the different treatments applied. Water storage replenishment and evolution is consequently also different during the plant growing period.

Estructure conditions in the arable layer and availability of water in the profile in each treatment cause differences in the development and yield crops.

REFERENCES


EFFECT OF MODERN TILLAGE SYSTEMS ON RESIDUE MANAGEMENT FOR CORN PRODUCTION

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University of Wisconsin¹ and University of Minnesota² (USA)

ABSTRACT

Four tillage systems were studied for seven years on Rozetta silt loam (fine-silty mixed, mesic, Typic Hapludalfs). The systems were: conventional (moldboard plow), chisel plow, slot plant, and ridge plant (paraplow in 1984 and 1985). Corn (Zea mays L.) was grown as the indicator crop. Each treatment was split into normal and mulched; on the slot plant, an additional treatment (bare) was established. On the other mulched treatments, the corn residue was added (for 60 to 80% cover) after tillage but prior to planting. Results showed nearly equal average yields for all treatments, except that no-till (slot plant) was slightly lower in several years. In 1984, 1985 and 1986 a trash-whip unit was compared to the coulter in the no-till treatment to reduce the in-row cover. The effect of reducing the in-row cover was to reduce the number of air growing degree days required to reach 50% silk and to reduce the grain moisture.

INTRODUCTION

Soil scientists have long appreciated the physical effect of tillage. F. H. King, U.W. Prof. of Agr. Physics, in his book "The Soil," published in 1895, gives us an insight that many have overlooked to this day when he stated: "The great importance of good tilth has always been appreciated by thoroughgoing practical men, and experience has abundantly taught that the stiffer and more resistant the soil, the greater should be the care and attention given to the field to bring it into perfect tilth before receiving the seeds or plants which it is expected to bring to maturity."

Corn has long been a basic crop in American agriculture (Peterson, 1960). The small clearings made by pioneers provided the soil, and a fish in every hill provided the fertilizer for many an excellent corn crop. The pioneers did not work the soil until it was completely pulverized and subject to rapid erosion in order to grow the corn. Mechanization developed tillage techniques for corn and other crops that became more and more destructive of our soil. Changing from the horse to tractor power has hastened the destruction of our soil by using this tremendous power to more rapidly destroy the structure of our soil with often needless tillage for row crops.
The physical characteristics desired in a seedbed are described by Browning (1950) and summarized as follows: (a) fine grain like granules or aggregates; (b) soil feels loose and mellow in your hand but not too loose for good germination; (c) sufficient large pores to allow rapid moisture movement during periods of intense rainfall; (d) granules and aggregates are in small clumps and not large clods, but they are stable and resist the beating action of raindrops.

Corn has long been accused of being an invitation to soil erosion. However, since the moldboard plow was invented more than 125 years ago, little effort has been made to produce corn without plowing. Scarseth (1952) reported that the trouble in producing corn is the method by which corn is being produced rather than the crop itself and that adequate fertilizing, properly timed and placed, may be the factor which can give sound cash profit foundation to "mulch corn tillage" and thereby result in a considerable improvement in soil and water conservation. With the development of the mulch planter (Poyner, 1950) an entirely new approach was possible. Hulbert and Wittmuss (1957) indicated that combining tilling and planting into one operation saves not only labor, but helps reduce water and wind erosion and tends to reduce weed growth. Even though Borst and Mederski (1957) (Cook et al., 1957) agreed that mulching reduces erosion, they indicated that mulch tillage is much more of an art than is conventional plowing and therefore may be extremely difficult to do a good job. Good yields from mulch tillage was reported as early as 1952 (Engelbert and Peterson, 1953) but weed problems made the practice unpopular until suitable herbicides were produced in the 1960's (Peterson, 1960).

Low spring soil temperatures frequently restrict the early growth of corn (Zea mays L.) in the northern Corn Belt (Van Wijk et al., 1959; Shaw, 1977). Such effects are most severe on poorly drained soils, on northern slopes, during cold springs, and where large amounts of surface residue are present. A quantitative assessment of the effects of tillage and residue management practices on soil temperature and the resulting influence on early growth and yield would considerably improve recommendations for tillage and soil management in this region. Gupta et al. (1983) observed only a minimal difference in spring soil temperature due to tillage-induced modification of soil thermal properties. However, major differences in spring soil temperature were caused by differences in surface residue cover. Other research supports the conclusion that the soil temperature response is primarily regulated by the energy available at the surface of the soil, which, in turn, is controlled by the degree of residue cover and the reflective and thermal properties of the residue and soil (Van Doren and Allmaras, 1978; Johnson and Lowery, 1985).
The object of this research was to determine the effect of tillage and surface residue cover on corn growth as expressed on grain moisture and yield.

METHODOLOGY AND MATERIALS

The study was conducted on the University of Wisconsin Agricultural Research Station at Lancaster, Wisconsin. The research site was located on Palsgrove silt loam and Rozetta silt loam (fine-silty, mixed, mesic Typic Hapludalfs), which are low in organic matter and moderately well and well drained, respectively. The site has a predominant slope of 9 to 10% with a northern aspect and is located on a contour strip immediately below a diversion. The soils on the site are Rozetta silt loam (fine-silty, mixed, mesic, Typic Hapludalfs) which is deep and moderately well-drained and a Palsgrove silt loam (fine-silty, mixed, mesic, Typic Hapludalfs) which ranges in depth from 0.6 to 1.25 m over red clay residuum and overlies bedrock (Swan et al., 1987).

Tillage systems used in this study were moldboard plow, wheeltrack, chisel, no-till, and ridge plant. Crop residue treatments were either no addition or removal (normal), or residue added after tillage but before planting (mulch), except for no-till, which had three residue levels: bare, normal, and double mulch residue. Tillage and residue effects on corn growth and yield are discussed in Swan et al. (1987). Within each tillage treatment, the individual residue treatments were at least 7 m in length and extended nearly the full width of the strip. The residue in all cases was corn stalks. The area had been in continuous corn for at least 10 yr prior to the study and was maintained in continuous corn during the study. The conventional (moldboard) treatment was plowed in April and secondary tillage with a disk was done soon after on the conventional and chisel treatments. The paraplow treatment was carried out in both fall 1983 and 1984; any effect observed in 1986 was due to residual effects of these earlier treatments. All plots were planted with a 4-row John Deere 7000 Max-Emerge planter equipped with fluted coulters on one side and "trash whip" units on the other side which removed residue from an 20 to 23 cm area over the row. The corn was planted in 90 cm corn rows.

RESULTS

Crop residue treatments and the surface residue cover over the entire area for the various tillage systems is grain in Table I.

The effect residue management by the trash whip on the various corn growth factors for the 1984 and 1985 are summarized using the paired T-test. The trash whip unit significantly increased:
DISCUSSION

The yield results with continuous corn at Lancaster show nearly equal yields from conventional tillage, ridge till, and chisel treatments. In 1986 and 1987 no-till (slot plant) was the highest yielding treatment. Thus farmers in the driftless soil area can choose between a variety of tillage options which have yields comparable to conventional tillage, but which are superior in soil and water conservation and offer savings in time, labor, and fuel compared to the conventional moldboard plow tillage method.

CONCLUSIONS

The in-row surface cover resulting from tillage and residue management can drastically affect the rate of corn development and early growth in the northern Corn Belt. These factors should be considered in selecting tillage systems in this region. Since the effect of moisture stress on corn yield varies with the stage of growth, systems for conservation tillage in the northern Corn Belt must include the effect of in-row residue cover.

REFERENCES


King, F.H., 1895. The soil. 305 p. MacMillian Co, N.Y.


TABLE I.


<table>
<thead>
<tr>
<th>Tillage system</th>
<th>Crop residue treatment+</th>
<th>Surface residue cover over entire area.</th>
</tr>
</thead>
<tbody>
<tr>
<td>No till</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bare</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>Normal</td>
<td>55</td>
<td>50</td>
</tr>
<tr>
<td>Double mulch</td>
<td>90</td>
<td>76</td>
</tr>
<tr>
<td>Chisel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td>11</td>
<td>12</td>
</tr>
<tr>
<td>Mulch</td>
<td>96</td>
<td>58</td>
</tr>
<tr>
<td>Moldboard</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Mulch</td>
<td>95</td>
<td>55</td>
</tr>
<tr>
<td>Paraplow</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Mulch</td>
<td>93</td>
<td>65</td>
</tr>
<tr>
<td>Ridge plant</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bare</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>Normal</td>
<td>46</td>
<td>20</td>
</tr>
<tr>
<td>Mulch</td>
<td>92</td>
<td>32</td>
</tr>
</tbody>
</table>

() Measured in rows with trash whip unit attached to planter to move surface crop residue from row area.

+ Bare-crop residue removed before planting (no prior tillage); normal-no removal or addition of crop residue; mulch-crop residue added after primary tillage; double mulch-crop residue addition to achieve 2x normal level of crop residue.

TABLE II.


<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Ridge plant</td>
<td>8.10</td>
<td>7.85</td>
<td>7.85</td>
<td>7.35</td>
<td>5.00</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>Slot plant</td>
<td>8.15</td>
<td>7.30</td>
<td>7.55</td>
<td>7.05</td>
<td>4.25</td>
<td>5.40</td>
<td>6.00</td>
<td>8.25</td>
<td>8.50</td>
</tr>
<tr>
<td>Chisel</td>
<td>8.00</td>
<td>7.50</td>
<td>8.35</td>
<td>7.70</td>
<td>4.75</td>
<td>5.75</td>
<td>6.27</td>
<td>8.30</td>
<td>8.30</td>
</tr>
<tr>
<td>Conventional</td>
<td>8.45</td>
<td>7.95</td>
<td>8.40</td>
<td>7.55</td>
<td>4.45</td>
<td>6.05</td>
<td>6.65</td>
<td>8.20</td>
<td>8.30</td>
</tr>
<tr>
<td>Paraplow*</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>5.30</td>
<td>6.25</td>
<td>8.10</td>
<td>8.40</td>
</tr>
</tbody>
</table>

* Fall 1983 and Fall 1984.
PLoughing, rotary cultivation and catch crop by growth of spring barley

Karl J. Rasmussen

Department of Soil Tillage, Soil Physics and Irrigation, Flensborgvej 22, DK 6360 Tinglev (Denmark)

ABSTRACT

Long term field experiments were carried out at 5 locations in Denmark over the years 1974-82. The experimental plan included ploughing and rotary cultivation to about 20 cm and 5-8 cm respectively and in combination with white mustard (Sinapis alba L.) as a catch crop. These treatments were compared with a crop rotation including 2 years barley and 1 year white mustard. The series consists of a total of 54 experiments. Yield decrease for continuous barley growing was greater after rotary cultivation than after ploughing in the autumn. Incorporating a catch crop by ploughing gave small yield increases, whereas incorporating by rotary cultivation gave small yield decreases. The effect of the catch crop on the following crop of barley was positive at low nitrogen-level and negative at high nitrogen-level. Green manure had only minimal influence upon the soil structure and upon the following crop of barley. Plant nutrients tended to be concentrated in the upper soil layer after reduced tillage. Reduced tillage gave a slight decrease in the porosity and the volume of coarse pores.

INTRODUCTION

In the end of the sixties and at the beginning of the seventies the interest for alternative, labour-saving and energy-saving tillage methods increased in Denmark. The reasons for this interest were among other things the rising energy prices and other costs related to soil tillage but also favourable foreign experiences with reduced tillage – especially in USA and England.

From the first Danish field research with alternative soil tillage methods started in the late sixties it was concluded, that tillage systems without ploughing had no common interest before couchgrass could be controlled in a chemical or biological way.

In the autumn of 1973 a series of long term field research started in different locations in Denmark. The aim of this research was to investigate soil tillage methods, and catch crops influence upon yield, grain quality, plant diseases, soil physical and chemical properties, and to investigate the influence of continuous barley growing in relation to barley in a crop rotation.
EXPERIMENTAL PLANS AND SOIL TYPES

At 5 locations in Denmark long term field research was carried out over the years 1974-82 after the following plans:

A. A crop rotation with white mustard (Sinapis alba L.) followed by two years barley

B. Continuous barley
   1. Ploughing without a catch crop
   2. Ploughing and incorporating a catch crop (Sinapis alba L.) used as green manure
   3. Rotary cultivation without a catch crop
   4. Rotary cultivation and incorporating a catch crop (Sinapis alba L.) used as green manure

The amounts of nitrogen given to the barley were normal N, -60 kg N, -30 kg N and +30 kg N per hectare.

The soil types were characterized as shown in Table I.

<table>
<thead>
<tr>
<th>Location</th>
<th>Soil type</th>
<th>Clay %</th>
<th>Humus %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jyndevad</td>
<td>coarse sand</td>
<td>4</td>
<td>2.9</td>
</tr>
<tr>
<td>Tylstrup</td>
<td>fine sand</td>
<td>7</td>
<td>2.1</td>
</tr>
<tr>
<td>Roskilde</td>
<td>sandy loam</td>
<td>10</td>
<td>2.9</td>
</tr>
<tr>
<td>Rønhave</td>
<td>sandy loam</td>
<td>14</td>
<td>2.0</td>
</tr>
<tr>
<td>Højer</td>
<td>silty loam</td>
<td>17</td>
<td>2.4</td>
</tr>
</tbody>
</table>

RESULTS

Barley continuous and in a crop rotation

In Table II first and second years barley are compared with continuous barley by ploughing and rotary cultivating respectively.

<table>
<thead>
<tr>
<th>Location</th>
<th>Crop rotation 1st year</th>
<th>Continuous Ploughing</th>
<th>Rotary cultivation</th>
<th>LSD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jyndevad*</td>
<td>28.9</td>
<td>-0.1</td>
<td>-2.3</td>
<td>1.7</td>
</tr>
<tr>
<td>Jyndevad**</td>
<td>47.4</td>
<td>-3.6</td>
<td>-5.6</td>
<td>2.1</td>
</tr>
<tr>
<td>Tylstrup</td>
<td>37.6</td>
<td>-5.4</td>
<td>-5.4</td>
<td>2.7</td>
</tr>
<tr>
<td>Roskilde</td>
<td>43.5</td>
<td>-2.7</td>
<td>-4.9</td>
<td>3.3</td>
</tr>
<tr>
<td>Rønhave</td>
<td>40.4</td>
<td>-1.1</td>
<td>-4.9</td>
<td>2.2</td>
</tr>
<tr>
<td>Højer</td>
<td>53.9</td>
<td>-10.8</td>
<td>-10.9</td>
<td>2.1</td>
</tr>
</tbody>
</table>

*no irrigation  **irrigation
First year barley gave the highest yield at all locations. Second year barley gave significant yield decreases on irrigated coarse sand, fine sand and on silty loam soil.

Continuous barley-growing also gave yield decreases compared to barley in a crop rotation, especially after rotary cultivation.

At all sites the yield decreases by the second year barley and continuous barley by ploughing declined with the rising amount of nitrogen given to the barley.

Ploughing, rotary cultivation and catch crop

The results of ploughing and rotary cultivation in combination with a catch crop are shown in Table III.

<table>
<thead>
<tr>
<th>Catch crop:</th>
<th>Ploughing</th>
<th>Rotary cultivation</th>
<th>LSD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-</td>
<td>+</td>
<td>---</td>
</tr>
<tr>
<td>Jyndevad*</td>
<td>28.8</td>
<td>2.5</td>
<td>-2.2</td>
</tr>
<tr>
<td>Jyndevad**</td>
<td>43.7</td>
<td>3.2</td>
<td>-2.0</td>
</tr>
<tr>
<td>Tylstrup</td>
<td>32.1</td>
<td>1.3</td>
<td>0.0</td>
</tr>
<tr>
<td>Roskilde</td>
<td>40.8</td>
<td>-1.6</td>
<td>-2.2</td>
</tr>
<tr>
<td>Rønhave</td>
<td>47.3</td>
<td>0.1</td>
<td>-3.8</td>
</tr>
<tr>
<td>Højer</td>
<td>43.1</td>
<td>1.9</td>
<td>-0.1</td>
</tr>
</tbody>
</table>

*no irrigation  **irrigation

Incorporating a catch crop by ploughing gave significant yield increases but only on coarse sand soil. Incorporating by rotary cultivation gave small yield decreases, but only significant on the sandy loam soil at Rønhave. Rotary cultivation without a catch crop gave yield decreases compared to ploughed soil but only significant on the coarse sand soil without irrigation and on the sandy loam soil at Rønhave.

The effect of the catch crop

The influences of the catch crop on the barley yield by ploughing and rotary cultivation are shown in Table IV at 4 nitrogen levels given to the barley. The effect was higher for incorporation by ploughing than by rotary cultivation.

<table>
<thead>
<tr>
<th></th>
<th>-60 kg N</th>
<th>-30 kg N</th>
<th>Normal N</th>
<th>+30 kg N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ploughing</td>
<td>2.9</td>
<td>1.8</td>
<td>0.8</td>
<td>0</td>
</tr>
<tr>
<td>Rotary cultivation</td>
<td>2.2</td>
<td>0.7</td>
<td>-0.4</td>
<td>-0.8</td>
</tr>
</tbody>
</table>
As an average of all locations there was a declining effect at increased nitrogen level.

Fig. 1 shows that even though there is a negative effect of the catch crop at increased level of nitrogen given to the barley (left) there is a positive but declining effect on the yield of nitrogen (right).

Soil chemical analyses

At the end of the field research in 1982 soil samples from the depth of 0-10 cm and 10-20 cm were taken for chemical analyses. As an average of all locations there were no differences between the treatments in the pH and P-index. The K-content in 0-10 cm depth was slightly higher after rotary cultivation than after ploughing but in the 10-20 cm depth no differences were found. There was a tendency of higher content of organic matter in the 0-10 cm depth after rotary cultivation and catch crop than in the other treatments.

Soil porosity

The soil porosity after ploughing and rotary cultivation at Jyndevad (coarse sand), Rønhave (sandy loam) and Højer (silty loam) is shown in Fig. 2.

In the silty loam soil the porosity was significantly higher after ploughing than after rotary cultivation in 0-50 cm depth. In the coarse sand and in the sandy loam no significant differences were found.

In the 5-10 cm depth the soil porosity was significantly highest after ploughing in the silty loam soil and significantly highest after rotary cultivation in the coarse sand and
the sandy loam soils. The reason for the differences between the soil types in this depth can be owing to the adjustment of the working depth of the rotary cultivator.

In the 15-20 cm depth the porosity at all 3 locations was highest after ploughing, but only significant in the silty loam soil.

In the 25-30 cm depth the porosity was the same after ploughing and rotary cultivation in the coarse sand and the silty loam soils but in the sandy loam soil the porosity was significantly lowest after ploughing which indicates a plough-pan.

![Porosity of the soil](image)

Fig. 2. Porosity of the soil, average 1977-82.

The volumes of coarse pores > 30 μm are shown in Fig. 3.

In the 5-10 cm depth the volume of coarse pores was highest after ploughing in the silty loam and the sandy loam soils but the differences were not significant.

In the 15-20 cm depth the volume of coarse pores was highest after ploughing in all of the soils but significant only in the coarse sand soil.
Aggregate stability

Analyses of topsoil aggregate stability on the 3 loamy soils are shown in Table V.

On the sandy loam soil at Roskilde the catch crop has improved the aggregate stability both after ploughing and after rotary cultivation. On the sandy loam at Rønhave and on the silty loam at Højel incorporating a catch crop by ploughing has not improved the aggregate stability, whereas rotary cultivation, especially in combination with a catch crop, has improved the aggregate stability.

<table>
<thead>
<tr>
<th>TABLE V. Per cent stable aggregates in 0-5 cm in the loamy soils 1979-82.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandy loam</td>
</tr>
<tr>
<td>Ploughing</td>
</tr>
<tr>
<td>Ploughing + catch crop</td>
</tr>
<tr>
<td>Rotary cultivation</td>
</tr>
<tr>
<td>Rotary cultivation + catch crop</td>
</tr>
</tbody>
</table>

LITERATURE


THE EFFECT OF DRIP-LINE PLACEMENT AND RESIDUE INCORPORATION ON THE GROWTH OF DRIP-IRRIGATED COTTON

E. RAWITZ, H. LIOR AND M. RIMON

1Faculty of Agriculture, The Hebrew University of Jerusalem, Rehovot (Israel)
2Agric. Extension Service, Israel Ministry of Agriculture
3Kibbutz Bror Hayil

ABSTRACT

Much of the cotton in Israel is grown under alternate-row drip irrigation. Plowing is giving way to precision tillage with a single implement that uproots, shreds and incorporates residues, chisels the soil and shapes beds in one pass. We investigated the relation between variability of growth in adjacent rows and methods of residue incorporation, presumed to interfere with water distribution if the drip lateral is not directly over the residue band. Large yield differences were found between centered and eccentric lateral placement, independent of the method of residue disposal. The yield differences are attributed to water availability as a function of distance between the plant row and the water source. However, the average yield of row pairs was the same regardless of lateral location, showing complete compensation between the more and less favored rows of a pair.

INTRODUCTION

Cotton is Israel's principal irrigated summer field crop, occupying some 50,000 hectares. About 65% of this area is drip-irrigated, and this percentage is steadily increasing. The most common practice is to plant the crop on two-row broad beds with a 97 cm (38 inch) row spacing, the drip laterals being placed between alternate rows, in the center of the bed. Cotton is customarily grown in the same field for three to five consecutive years, with wheat sometimes grown in the winter. The available growing season is too short for the grain to mature, and the crop is harvested for silage in the spring. The time available between the cotton harvest and the onset of the winter rains, as well as between the wheat harvest and cotton planting in the spring, is a major limiting factor for the execution of tillage operations.

It is a requirement of the production system to control the pink boll worm, and one effective way of doing this is to interrupt its life cycle by denying it hosts for overwintering, such as regrowth of cotton stubble, seeds and other crop residues on the soil surface. By an executive order which has the power of law, all cotton residues must be removed from the fields during November.
Until about 1980, the standard tillage sequence after harvest consisted of chopping the stover with a horizontal blade rotary chopper, and turning it under by a three- or four-bottom two-way plow working to a depth of 35-40 cm. This operation was carried out on dry, compacted soil, turned up large, hard clods instead of a furrow slice, had a very high energy requirement, and was time consuming. If wheat were to be sown, the clods had to be broken down in the dry state by repeated disk ing, pulverizing a large part of the soil, which then tended to crust under raindrop impact and produce runoff and erosion. If left in winter fallow, secondary tillage after onset of the rains was by repeated disk ing, cultivation or harrowing followed by ridging or bed construction. Thus the final seedbed was prepared gradually during the winter, with up to seven trips over moist soil. During winters with frequent rains many farmers did not manage to prepare the seedbed by sowing time without either working at non-optimal moisture or omitting some of the steps. Some of the secondary tillage passes were perpendicular or diagonal to the direction of plowing, and thus over a few years a field could be compacted in a random pattern, with a steadily decreasing distance between wheel tracks (Frede, 1982). Eventually, there were noted symptoms such as variability of yields within and between fields, gradual, slight decreases in average yields, increased runoff and declining soil infiltrability, which added up to the hard-to-prove suspicion that the prevailing tillage system was causing structure deterioration due to compaction (Hadas et al., 1983).

Tentative steps were taken towards precision tillage in permanent controlled traffic lanes and minimum or reduced tillage based on subsoiling and integration of several implements in a "multitiller", e.g., a combination subsoiler-rototiller-ridger. However, field sanitation, especially the elimination of stubble which could regrow, was not as good as with deep plowing. A tillage system based on an entirely new concept became possible with the development by a local engineering firm of the Uprooter-Shredder-Mulcher (USM). This machine basically pulls the cotton plant including the major root system out of the soil, conveys it to a chopper assembly, and ejects the shredded material. Several versions have been built around the basic system, giving the following options:

1) Disposal of chopped residues
   a) broadcast over the land surface
   b) blown into a wagon (similar to forage harvester)
   c) blown into a subsoiler slot (vertical mulching)

2) Additional implements mounted on USM or tool bar
   a) mulching shank with funnel (required for 1c)
   b) subsoiler shanks
   c) ridgers or bed shaper

Option 1a requires incorporation of residues in the soil by a subsequent pass of a rotary tiller, which does not leave the soil surface completely clean of residues. It is used only if the following crop is not cotton. Option 1b
envisions either use of the residues as fuel, or returning them to the land after composting, the heat presumably killing the bollworm eggs. Option 1c is the one commonly used. The long-term effects of the various versions of this tillage system are not yet known, and are presently under investigation. However, it was observed that the USM deposits the shredded residues as a "pipe" at a depth of about 30 cm in the center of the beds, and that the material preserved its physical integrity into the following summer. It was recognized that this could affect the soil wetting pattern of water delivered by the drip lateral, also placed in the center of the bed. Indeed, in the summer of 1985, following a winter with low rainfall which did not wet the profile deeply, reports were received of uneven growth in many fields, with the variability apparently random and affecting small areas. The hypothesis was proposed that this was due to a combination of the residue "pipe" and drip lateral placement. The laterals can not be placed perfectly on center and in a straight line, and it appeared that if the lateral crossed over from one side of the residue "pipe" to the other, alternately one or the other of a pair of plant rows on a bed would get less water, thus producing the observed spotty growth. This was perceived as undesirable, although no clear effect on yields was determined. An experiment was therefore initiated in the fall of 1985 to investigate the relative effects of drip lateral placement and residue disposal method.

METHODS

The experiment included four residue disposal treatments and two lateral placement treatments in a split-plot design, in four replications, each plot 2 rows wide and 15 m long:
A. complete removal of residues
   incorporation at 30 cm depth
   shallow incorporation (15 cm)
   shallow incorporation and mixing with soil
B. drip lateral fixed on centerline of bed
   drip lateral fixed 30 cm off center

Data obtained included straw yield in the fall preceding the experiment, plant population density, plant height, and yield of seed cotton determined separately for each row of the pair irrigated by a given lateral. Picking was done by hand, of the central 10 m of the 15-m plot length.

RESULTS

Plant density in the spring of 1986 was 9.0 per meter of row with a standard deviation of 0.8 plants per meter, with no significant differences between the two rows of a bed. Maximum plant height, at the beginning of August, likewise showed no treatment effect. A summary of the yields and their analysis is given in Tables I and II.
Table I: Comparison of seed cotton yield by residue disposal and drip lateral placement treatments, Mg/ha

<table>
<thead>
<tr>
<th>Residue Treatment</th>
<th>Lateral Placement</th>
<th>Centered</th>
<th>Excentric</th>
<th>Yield</th>
<th>s.d.</th>
<th>Yield</th>
<th>s.d.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Removal</td>
<td></td>
<td></td>
<td></td>
<td>4.59</td>
<td>0.42</td>
<td>4.72</td>
<td>0.63</td>
</tr>
<tr>
<td>Incorporation, 30 cm</td>
<td></td>
<td></td>
<td></td>
<td>4.59</td>
<td>0.62</td>
<td>4.66</td>
<td>0.42</td>
</tr>
<tr>
<td>Incorporation, 15 cm</td>
<td></td>
<td></td>
<td></td>
<td>4.37</td>
<td>0.40</td>
<td>4.46</td>
<td>0.71</td>
</tr>
<tr>
<td>Mixed with soil</td>
<td></td>
<td></td>
<td></td>
<td>5.03</td>
<td>0.79</td>
<td>4.63</td>
<td>0.83</td>
</tr>
</tbody>
</table>

Average 4.64 4.62

None of the above differences is significant.

Table II: Comparison of yields from rows within a pair as a function of lateral placement and residue disposal

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Removal</td>
<td>4.78 0.54</td>
<td>4.40 0.16</td>
<td>5.25 0.27</td>
<td>4.20 0.33</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Incorpor'n.(avg. of all trtmt's)</td>
<td>4.54 0.45</td>
<td>4.79 0.80</td>
<td>5.08 0.26</td>
<td>4.10 0.44</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Overall average 4.63 0.47 4.63 0.63 5.15 0.26 4.14 0.39

The differences between residue removal and incorporation are not significant, nor are the differences between the right and left rows on beds with centered lateral placement. However, with excentric lateral placement, the rows nearer the lateral gave significantly higher yields.
DISCUSSION

The yield data clearly show that excentric drip lateral placement between a pair of rows on a bed produced a large difference in yield between the rows, on the order of 1 Mg/ha. However, the averaged yield of two rows on the same bed was equal to that of beds with centered laterals, so that the higher yield of the row nearer the lateral fully compensated for the lower yield of the far row.

The data also indicate that in this case the method of residue management had no effect on yield. The residue "pipe" apparently did not interfere with soil water distribution in a way that would depress yield, although this is not to say that it did not or could not affect the water or root distribution pattern. The observed yield difference between adjacent rows can simply be attributed to insufficient supply of water to the plants in the far row. The placing of drip laterals in only every other interrow space was adopted by the growers in order to save on equipment costs. It was known that somewhat higher yield can be obtained by placing a lateral in every interrow space, but this did not pay for the additional equipment (Oron et al., 1981). Thus the deliberately limited and asymmetrical root system is associated with an optimal yield which is somewhat less than maximum yield due to slightly inadequate water availability. Any additional factor affecting the water supply, in this case distance between the plant and the water source, can thus be expected to affect yield.

If one could rely on full compensation between more and less favored plants in adjacent rows under all expectable conditions of lateral displacement from the center, uniformity of stand, and initial soil water storage, the suspected problem could be declared to be non-existent. However, Hadas et al. (1985) have shown that stand heterogeneity may have greater or lesser effect on yield, depending on the presence of other limiting factors such as average stand density, nutrient and water availability. In fields with a high yield potential, heterogeneity is generally more deleterious. There appear to be at least potential advantages in eliminating heterogeneity due to drip lateral positioning. During the 1987 growing season some growers tried to hold drip lines on center by placing them in shallow furrows. No problems were reported, but this was attributed to the large root-zone water reserve following an unusually wet winter. The tests were thus inconclusive.

CONCLUSIONS

1. Imperfectly centered drip laterals between adjacent cotton rows produced large yield differences between the rows, indicating that yield of the far rows was limited by insufficient water supply.

2. The above yield differences occurred regardless of various residue disposal practices, including complete
removal, different placement depths and degree of mixing with the soil. Residue placement was therefore not the cause of the yield differences.

3. The yield differences are attributed to distance between the plant and the water supply.

4. The average yield of row pairs was the same for centered and eccentric drip laterals, which may however not be the case under all conditions.

ACKNOWLEDGEMENT

This work was supported in part by a grant from BARD, U.S.-Israel Binational Agricultural Research and Development Fund.

REFERENCES


IN-ROW TILLAGE METHODS FOR SUBSOIL AMENDMENT AND STARTER FERTILIZER APPLICATION TO STRIP-TILLED GRAIN SORGHUM

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ABSTRACT

Acid subsoils and tillage pans limit crop yields on sandy soils of the Southern Coastal Plain of the USA. Studies were conducted for 3 years at 2 locations with acid subsoils and tillage pans to determine the effect of starter fertilizer (22 kg N, 10 kg P/ha) and liquid lime (1350 kg/ha) placement with in-row tillage methods on growth and yield of grain sorghum (Sorghum bicolor (L.) Moench) grown in a conservation-tillage system. The starter fertilizer and lime were applied in factorial combinations in the in-row subsoil channel, in a narrow (4 mm) slit 18 cm below the tillage pan (slit-tillage), or 7 cm to the side of the row incorporated 7 cm deep. Starter placement was not critical, but response to starter occurred only when deep tillage, either in-row subsoiling or slit-tillage, was used in conjunction with the fertilizer. There was no benefit from injecting lime.

INTRODUCTION

In many Ultisols of the southeastern USA, yield-limiting water stress is induced by restriction of root growth to the surface soil as a result of subsoil acidity (Adams, 1984) and the presence of genetic or traffic-produced pans (Campbell et al., 1974; Kashirad et al., 1967). Subsoiling is frequently used to disrupt root-restricting pans in these soils and planters are available that incorporate in-row subsolvers in their design. Although subsoiling can increase yields (Touchton et al., 1986; Reeves and Touchton, 1986; Reeves et al., 1986), the practice requires large amounts of energy, reduces planting speed, often results in erratic stands, and can cause undesirable mixing of soil horizons. An energy saving alternative to subsoiling has been developed that promotes root growth through hardpans so that crops can access water and nutrients in the subsoil (Elkins and Hendrick, 1983). Slit-tillage, as it is called, results in a surface-tilled, 20-cm wide seedbed and a 4 mm wide vertical slit through the hardpan.

Application of N-P starter fertilizers with in-row subsoiling has proved beneficial for cotton (Touchton et al., 1986), and corn (Reeves et al., 1986) grown on easily-compacted, coarse-textured soils. Crops grown with conservation tillage may especially benefit from starter fertilizer applications. The acid subsoils of the southeastern United States can restrict root growth through Al toxicity and Ca deficiency (Adams, 1984). Root growth through the opening in the hardpan of acid subsoils provided by slit-tillage might be enhanced by the injection of amendments such as starter fertilizers and liquid lime.
The objectives of these field studies were to: 1) compare slit-tillage to the more common practice of in-row subsoiling as a means of improving crop performance in compacted soils; 2) determine if deep placement of lime is of benefit in improving crop growth and yield in soils with acid subsoils; and 3) determine the effect of starter fertilizer on growth and yield of conservation-tiled grain sorghum as influenced by in-row tillage/placement method.

MATERIALS AND METHODS
Tests were conducted for 3 years (1985-1987) on a Hartsells fine sandy loam (fine-loamy, siliceous, thermic Typic Hapludults) in northeastern Alabama (USA) and for 2 years (1986-1987) on a Norfolk sandy loam (fine-loamy, siliceous, thermic Typic Paleudults) in west central Alabama. A different site was used in 1985 than in 1986-87 at the Hartsells location. Soils at both locations had a 4-8-cm tillage or traffic pan located 25-35 cm below the surface. Initial soil pH averaged 6.5, and 5.3 for the 0-25 and 25-45 cm depths, respectively, on the Hartsells soil sites, and 5.7 and 4.5 for respective depths on the Norfolk soil. On the Norfolk soil, an application of 2.2 t/ha dolomitic limestone in the winter of 1986 raised the pH in the top 20 cm to 6.1 prior to planting in 1987. Ammonium nitrate to supply 134 kg-N/ha was banded beside each row 4-5 weeks after planting in all tests.

Grain sorghum (Sorghum bicolor (L.) Moench) was planted into a winter cover crop of rye (Secale cereale L.) at the Hartsells location on 22 May 1985, 14 May 1986, and 29 May 1987. Planting dates at the Norfolk location were 24 April 1986, and 5 June 1987. A 4-row no-till planter was used to seed 250,000 seed/ha in 75-cm row widths. Four-row plots, 9.1-m long, were used in all tests. The front tool bar of the planter was equipped with smooth coulters for cutting through residue, straight-shank subsolvers to subsoil in-row, and a pair of angled, fluted coulters to close the subsoil channel and till a narrow (20-cm wide) seedbed. Planter units, each consisting of a double-disk opener, seed hopper, and angled, hard-rubber press wheels, were attached to the rear tool bar. Subsoiler shanks were removed to plant no-till. Modified subsoiler shanks were used to perform slit-tillage. Shortened shanks were fitted with a 4-mm thick X 18-cm long triangular bladelike fin beneath the foot of each shank. A detailed description of this tool has been described (Elkins and Hendrick, 1983). Depth of tillage for subsoiled and slit-till treatments was the same (40 cm). The foot of the modified slit-till Shank was pulled through the soil above the pan, at a depth of 22-24 cm; the slit blade extended through the pan, an additional 18 cm below the foot of the subsoiler. In appropriate treatments, solution fertilizer to supply 22 kg-N and 10 kg-P/ha was displaced with an electric pump into: 1) the bottom 10-15 cm of the subsoil channel; 2) into the slit channel; or 3) 7-cm beside the row, incorporated 7-cm deep with fluted coulters. Liquid-lime suspension was displaced with a PTO driven pump to supply 1350 kg/ha lime in a similar manner.

In 1985 on the Hartsells soil, the experimental design was a factorial arrangement of 3 tillage methods X 4 amendments in a randomized block of 4 replications. Tillage treatments
were: 1) slit-till; 2) no-till (amendments incorporated 7-cm beside the row and 7 cm deep with fluted coulters); and 3) subsoiling. Amendment treatments were: 1) N-P starter fertilizer; 2) lime; 3) starter + lime; and 4) no amendment check. In 1986 and 1987, on all tests, the design was an incomplete factorial of 4 replications; treatments expanded from those used in 1985 to include 7 X 7 cm placement of amendments with deep tillage treatments (subsoil and slit-till) and deep-placed lime with 7 X 7 cm placed starter fertilizer.

Whole plant samples for dry weight determinations were taken from 1-m of row 5-6 weeks after planting. At maturity, grain yields were taken from the middle 2 rows and adjusted to 130 g/kg moisture.

Data were subjected to appropriate analysis of variance for each design model. Fisher's protected least significant difference (P ≤ 0.10) and single degree of freedom tests were used for mean separation of preplanned comparisons.

RESULTS AND DISCUSSION

Hartsells Location

In 1985, substantial increases in early-season plant growth occurred only when starter fertilizer or starter + lime was applied in conjunction with some form of deep in-row tillage (Table I). Treatment effects on grain yield generally followed the same trend as for plant growth (Table I). Maximum grain yield (5175 kg/ha) occurred when starter fertilizer was applied in the subsoil channel. Averaged over amendments, yields were 4302, 4053, and 3741 kg/ha (LSD 0.10 =230 kg/ha) for subsoiling, slit-till, and no-till, respectively.

In 1986 there were no treatment effects on early-season plant growth or grain yield other than an increase in yield from subsoiling compared to no-till plots (5239 vs. 4943 kg/ha, P≤ 0.11).

In 1987, subsoiling resulted in reductions in early-season plant growth compared to no-till and slit-tillage (Table II). However, this reduction did not result in differences in grain yield between subsoiled plots and no-till plots (Table II). Slit-tillage significantly increased yield compared to no-till and subsoiling. Starter fertilizer and lime had no effect on early-season plant growth or yield. Elkins et al. (1983) reported that root growth into slits maintained the integrity of slits, resulting in an increased effect on crop performance with successive growing seasons. The superior performance of slit-till in this, the second year on this tier, is compatible with results previously reported (Elkins et al., 1983).

Norfolk Location

In 1986, rainfall during the period extending 84 days after planting totaled 6 cm, 22 cm below the 30-year norm. Although early-season plant growth was improved by subsoiling and slit-tillage (Table III), an outbreak of anthracnose (Colletotrichum graminicola) resulted in extremely low yields,
with no differences in yield due to treatments (Tables III and IV). Starter fertilizer increased early-season growth only when applied with some form of deep tillage, either subsoiling or slit-till (Table IV).

In 1987, subsoiling and slit-tillage resulted in equivalent increases in early-season growth over no-till (Table III). Although yields were low due to a severe drought from bloom through physiological maturity, the increased growth from deep tillage was mirrored in commensurate yield increases (Table III). As in 1986 at this location, application of N-P starter in conjunction with some form of deep tillage (either subsoiling or slit-tillage) resulted in increased early-season plant growth (Table IV). Amendments had no effect on grain yield, however.

CONCLUSIONS

1. There was no benefit to plant growth or grain yield from injecting lime below the tillage pan in any location-year.
2. In years when early-season growth and grain yield responded to in-row deep tillage, slit-tillage was as effective as subsoiling. At the Hartsells location, which was not subjected to severe drought stress in any year, slit-till resulted in improved crop performance compared to subsoiling in the second year of the test on the same site.
3. Applying N-P starter fertilizer in conjunction with deep tillage, either subsoiling or slit-till, increased early-season growth in 3 of 5 location-years. A nonsignificant trend occurred in the remaining 2. Placing the N-P in the subsoil channel or slit was no more effective than incorporating it beside the row.
4. Although early-season growth responded consistently to starter fertilizer applied in conjunction with deep tillage, yield response was highly dependent on rainfall. Yield response to starter fertilizer occurred in only 1 location-year.

TABLE I

Early season growth and grain yield of sorghum grown on a Hartsells soil in 1985 as affected by amendment and in-row tillage/placement.

<table>
<thead>
<tr>
<th>Tillage/Placement</th>
<th>Amendment</th>
<th>None</th>
<th>Lime</th>
<th>Starter</th>
<th>Starter + Lime</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>plant growth, g dry matter/ 1-m row</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slit</td>
<td></td>
<td>18.7</td>
<td>22.0</td>
<td>43.6</td>
<td>39.0</td>
</tr>
<tr>
<td>Subsoil</td>
<td></td>
<td>19.4</td>
<td>21.0</td>
<td>65.0</td>
<td>36.4</td>
</tr>
<tr>
<td>7 X 7</td>
<td></td>
<td>14.4</td>
<td>14.4</td>
<td>24.6</td>
<td>21.7</td>
</tr>
<tr>
<td>LSD (0.10)=9.84</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

--------grain yield, kg/ha--------

| Slit            | 3640 | 3837 | 4354 | 4628 |
| Subsoil         | 4385 | 4088 | 5175 | 4172 |
| 7 X 7           | 3648 | 3655 | 4126 | 3579 |
| LSD (0.10)=518  |      |      |      |      |
TABLE II

Early-season growth and grain yield of sorghum grown on a Hartsells soil in 1987 as affected by in-row tillage methods.

<table>
<thead>
<tr>
<th>Comparison</th>
<th>Dry Wt. ( g/\text{m row} )</th>
<th>( P &lt; )</th>
<th>Grain Yield ( \text{kg/ha} )</th>
<th>( P &lt; )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subsoil</td>
<td>48.1</td>
<td>0.02</td>
<td>3984</td>
<td>0.91</td>
</tr>
<tr>
<td>No-till</td>
<td>57.3</td>
<td></td>
<td>3962</td>
<td></td>
</tr>
<tr>
<td>Slit-till</td>
<td>55.8</td>
<td>0.66</td>
<td>4307</td>
<td>0.08</td>
</tr>
<tr>
<td>No-till</td>
<td>55.8</td>
<td>0.02</td>
<td>3984</td>
<td>0.04</td>
</tr>
</tbody>
</table>

TABLE III


<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dry Wt. ( g/\text{m row} )</td>
<td>( P &lt; )</td>
<td>Yield ( \text{kg/ha} )</td>
<td>( P &lt; )</td>
</tr>
<tr>
<td>Subsoil</td>
<td>14.3</td>
<td>0.001</td>
<td>481</td>
<td>0.36</td>
</tr>
<tr>
<td>No-till</td>
<td>6.2</td>
<td>0.92</td>
<td>399</td>
<td>0.49</td>
</tr>
<tr>
<td>Slit-till</td>
<td>12.7</td>
<td>0.001</td>
<td>399</td>
<td>0.49</td>
</tr>
<tr>
<td>No-till</td>
<td>6.2</td>
<td>0.001</td>
<td>399</td>
<td>0.49</td>
</tr>
<tr>
<td>Slit-till</td>
<td>12.7</td>
<td>0.001</td>
<td>399</td>
<td>0.49</td>
</tr>
</tbody>
</table>

TABLE IV


<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dry Wt. ( g/\text{m row} )</td>
<td>( P &lt; )</td>
<td>Yield ( \text{kg/ha} )</td>
<td>( P &lt; )</td>
</tr>
<tr>
<td>Lime Deep</td>
<td>7.6</td>
<td>0.92</td>
<td>388</td>
<td>0.44</td>
</tr>
<tr>
<td>No Lime</td>
<td>7.4</td>
<td>0.92</td>
<td>502</td>
<td>0.44</td>
</tr>
<tr>
<td>N-P + deep till</td>
<td>17.6</td>
<td>0.92</td>
<td>493</td>
<td>0.34</td>
</tr>
<tr>
<td>No N-P + deep till</td>
<td>7.4</td>
<td>0.001</td>
<td>502</td>
<td>0.94</td>
</tr>
<tr>
<td>N-P + no-till</td>
<td>7.2</td>
<td>0.92</td>
<td>247</td>
<td>0.64</td>
</tr>
<tr>
<td>No N-P + no-till</td>
<td>4.5</td>
<td>0.42</td>
<td>344</td>
<td>0.64</td>
</tr>
<tr>
<td>N-P deep</td>
<td>18.8</td>
<td>0.92</td>
<td>551</td>
<td>0.34</td>
</tr>
<tr>
<td>N-P 7 X 7</td>
<td>16.5</td>
<td>0.32</td>
<td>436</td>
<td>0.44</td>
</tr>
</tbody>
</table>
REFERENCES


TILLAGE AND ROTATION INFLUENCES ON SOIL ENVIRONMENT

D. H. RICKERL, W. B. GORDON and J. D. SMOLIK

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ABSTRACT

Field studies were begun in 1985 to investigate long-term effects of crop rotation/tillage systems on soil physical properties in South Dakota, U.S.A. In the Alternate system, primary tillage was fall discing and the crop rotation was oat/alfalfa, alfalfa, soybean, corn. Tillage in the Conventional system was moldboard plow after spring wheat and the Ridge-till system was chiseled after spring wheat, and ridged at second corn cultivation. The rotation in the Conventional and Ridge-till was corn, soybean, and spring wheat. Soil frost depth from shallow to deep was oat/alfalfa < corn < wheat, alfalfa < soybean. At spring wheat planting, soil temperatures were 10°C and 20°C with soil moisture of 30% and 17% for oat/alfalfa and soybean residues, respectively. In the Ridge system, soil temperatures were 8°C warmer and soil moisture was 6% lower on the ridge top than the ridge furrow.

INTRODUCTION

Farming systems incorporate many factors which influence soil physical properties. These factors include cropping sequence, tillage, and agricultural chemical use. Studying the entire system allows the determination of interactions between soil variables and farming inputs. The objectives of this study were to determine long-term effects of crop rotations, tillage, and agricultural chemical inputs on soil physical properties.

METHODS

Field studies were begun in 1985 on a Brookings silty clay loam, classified as a silty mixed Pachic Udic Haploboroll, near Watertown, South Dakota, USA. Three farming systems were established: Alternate (Alt), Conventional (Conv), and Ridge-till. The test was a randomized complete block replicated 4 times. The cultural practices involved in these systems are summarized in Table I. Tillage treatments were no moldboard plow in the Alternate, moldboard plow after spring wheat in the conventional, and fall chisel plow after spring wheat in the Ridge-till. In the Ridge-till system, ridges were formed in spring wheat stubble, corn was...
### Table I

**Cultural practices for each farming system**

<table>
<thead>
<tr>
<th>Farming System</th>
<th>Crop</th>
<th>Pre-Plant</th>
<th>Post Plant</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Alternate</em></td>
<td>Corn ((Zea \textit{mays} \textit{L.}))</td>
<td>Field cultivate + harrow, disk</td>
<td>rotary hoe cultivate, fall disk</td>
</tr>
<tr>
<td></td>
<td>Soybean ((\textit{Glycine \textit{max} L. \textit{Merr}}))</td>
<td>Field cultivate, disk</td>
<td>rotary hoe, cultivate</td>
</tr>
<tr>
<td></td>
<td>Oat/Alfalfa ((\textit{Avena \textit{sativa} L.})) ((\textit{Medicago \textit{sativa} L.}))</td>
<td>Field cultivate, + harrow, disk</td>
<td>---</td>
</tr>
<tr>
<td></td>
<td>Alfalfa</td>
<td>---</td>
<td>subsurface sweep, fall chisel</td>
</tr>
<tr>
<td><em>Conventional</em></td>
<td>Corn</td>
<td>Field cultivate + harrow</td>
<td>cultivate, fall disk</td>
</tr>
<tr>
<td></td>
<td>Soybean</td>
<td>Disk</td>
<td>cultivate</td>
</tr>
<tr>
<td></td>
<td>Wheat ((\textit{Triticum \textit{aestivum} L.}))</td>
<td>Field cultivate + harrow</td>
<td>fall plow</td>
</tr>
<tr>
<td><em>Ridge</em></td>
<td>Corn</td>
<td>---</td>
<td>cultivate and ridge at last cultivation</td>
</tr>
<tr>
<td></td>
<td>Soybean</td>
<td>---</td>
<td>cultivate</td>
</tr>
<tr>
<td></td>
<td>Wheat</td>
<td>Field cultivate + harrow</td>
<td>fall chisel and ridge</td>
</tr>
</tbody>
</table>

Planted with minimum disturbance, and ridges were rebuilt at second cultivation. Soybeans were planted on existing ridges, but not re-ridged at cultivation. Crop rotations were corn-soybean-spring wheat in the Conventional and Ridge-till treatment and oat/alfalfa-alfalfa-soybean-corn in the Alternate system. Soil frost tubes (Ricard et al., 1976) were installed in each plot to a depth of 120 cm. Frost depth was recorded weekly beginning 23 January and continuing until 4 April. Tubes were removed just prior to spring wheat planting. At that time (16 April) soil temperature was recorded and samples were collected to determine, gravimetric soil moisture and bulk density in the top 20 cm.
After fall harvest, percent residue covering the soil was counted and soil moisture was determined at 0 - 20, 20 - 60, and 60 - 120 cm depths.

RESULTS

During the 1986 winter, there was no snow cover and soil frost was deepest in February. In Conventional and Ridge-till systems, soybean producing soils froze deeper than corn producing soils (Figs. 1 and 2). In the Alternate system, the pattern of frost depth was similar for corn, soybean, and alfalfa (Figs. 3 and 4). Depths of frost in wheat were similar for Ridge-till and Conventional, and were intermediate between corn and soybean treatments (Fig 5). However, in mid-March, wheat which had been ridged for the following corn crop, exhibited dramatic fluctuations in frost depth. Soils producing oat/alfalfa were consistently shallow in frost depth.

At the time of spring wheat planting, oat/alfalfa residues which served as insulators during winter months kept soils cool and damp (Table II). Soil temperatures in the top 20 cm were higher in the wheat treatment which had been turned than in the disked corn and soybeans. Ridging allowed the soil to warm rapidly on the ridge tops, but remain cool in the furrow. Ridge-till also dried corn and wheat soils more rapidly than soybean areas which were not ridged.

Table II

The effect of tillage system and previous crop residue on soil physical properties on 16 April 1987

<table>
<thead>
<tr>
<th>Previous Crop Residue</th>
<th>Temperature (°C)</th>
<th>Moisture (%)</th>
<th>Bulk Density (g/cc)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Alt¹ Conv Ridge</td>
<td>Alt Conv Ridge</td>
<td>Alt Conv Ridge</td>
</tr>
<tr>
<td>Corn</td>
<td>17</td>
<td>15</td>
<td>16/15</td>
</tr>
<tr>
<td>Soybean</td>
<td>17</td>
<td>16</td>
<td>20/15</td>
</tr>
<tr>
<td>Wheat</td>
<td>--</td>
<td>20</td>
<td>17/12</td>
</tr>
<tr>
<td>Oat/Alfalfa</td>
<td>10</td>
<td>--</td>
<td>30</td>
</tr>
<tr>
<td>Alfalfa</td>
<td>16</td>
<td>--</td>
<td>25</td>
</tr>
</tbody>
</table>

¹ Alt is the Alternate and Conv is the Conventional tillage system.

b Temperature at 20 cm depth.

c Ridge top ridge furrow temperatures.

d Moisture in the top 20 cm.
Soil bulk density reflected tillage systems. The Alt alfalfa (undercut), Conv wheat (turn-plow) and Ridge wheat (chisel plow) had the lowest bulk densities. Ridged corn and soybeans and Alt soybean were intermediate in bulk density (1.3 - 1.4 g/cc). Alt corn, and Conv corn and soybeans, which had been disked only, had the highest bulk density.

Fall crop residue cover also reflected tillage. Alternate alfalfa (undercut) and Conv wheat (turn-plow) averaged 28.5% cover (Table III). Alt oat/alfalfa and Ridge-till wheat had the most cover, averaging 95%. Ridging in the fall wheat stubble reduced bulk density while maintaining residue cover. Averaging across other treatments, residue cover was 67.7%.

Table III

Fall residue as affected by previous crop and tillage system.

<table>
<thead>
<tr>
<th>Previous Crop</th>
<th>Alternate</th>
<th>Conventional</th>
<th>Ridge-till</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td>61^a</td>
<td>66</td>
<td>66</td>
</tr>
<tr>
<td>Soybeans</td>
<td>66</td>
<td>78</td>
<td>69</td>
</tr>
<tr>
<td>Wheat</td>
<td>--</td>
<td>26</td>
<td>91</td>
</tr>
<tr>
<td>Oat/Alfalfa</td>
<td>99</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Alfalfa</td>
<td>31</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

^a Percent residue cover after fall tillage, measured 20 November, 1987.

Soil moisture after fall harvest was generally slightly higher for soybean than corn (Table IV). In both row crops, soil moisture decreased as you moved down the profile. However in the alfalfa and oat/alfalfa, soil moisture was greater at the 20 - 60 cm depth than the other two depths. Wheat tended to have less soil moisture in the Ridge-till than the Conventional.

This study has just begun, and conclusions can not be drawn from only one year of data. As the research continues, long term effects of farming systems on soil physical properties will be reported.
### Table IV

Fall soil moisture, at three depths, as affected by previous crop and tillage system

<table>
<thead>
<tr>
<th>Previous Crop</th>
<th>Depth</th>
<th>Soil moisture (%) for indicated tillage system</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Alternate</td>
</tr>
<tr>
<td>Corn</td>
<td>0 - 20</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>20 - 60</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>60 - 120</td>
<td>11</td>
</tr>
<tr>
<td>Soybean</td>
<td>0 - 20</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>20 - 60</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>60 - 120</td>
<td>10</td>
</tr>
<tr>
<td>Wheat</td>
<td>0 - 20</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>20 - 60</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>60 - 120</td>
<td>--</td>
</tr>
<tr>
<td>Oat/Alfalfa</td>
<td>0 - 20</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>20 - 60</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>60 - 120</td>
<td>9</td>
</tr>
<tr>
<td>Alfalfa</td>
<td>0 - 20</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>20 - 60</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>60 - 120</td>
<td>10</td>
</tr>
</tbody>
</table>

### REFERENCES


![Fig. 1 Frost depth in corn and soybean soils with Conventional tillage.](image-url)
Fig. 2 Frost depth in corn and soybean soils with Ridge-tillage.

Fig. 3 Frost depth in corn and soybean soils in the Alternate tillage system.

Fig. 4 Frost depth in oat/alfalfa and alfalfa soils in the Alternate tillage system.

Fig. 5 Frost depth in wheat soils in the Conventional and Ridge-tillage systems.
SOIL TILLAGE AND NITROGEN FERTILIZING ON DURUM WHEAT IN SOUTHERN ITALY

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ABSTRACT

This research, started in 1982-83, was carried out on a silty clay loam soil (Typic Chromoxerert) of southern plain, featured by hot-dry summers and cold-moist, rainy winter seasons.

Four tillage methods were compared (A, conventional mouldboard ploughing; B, ripper subsoiling; C, surface disc-harrowing; D, minimum tillage with rotary hoeing) on a durum wheat continuous cropping (cv.Isa), thus investigating their interaction with four nitrogen doses (a, 0; b, 50; c, 100; d, 150 kg N ha\(^{-1}\)).

Conventional tillage showed better yield responses, together with lower weed amounts. No considerable variation was observed among the other methods compared, notwithstanding the remarkable production variability among years, brought about by the seasonal climatic trends.

The increasing nitrogen doses confirmed that nitrogen fertilizing may reduce crop production in the trial environment, particularly at high doses.

Such effects played major role on conventional tillage.

INTRODUCTION

Soil tillage represents a problem of mounting concern nowadays for the scientific world, because of its energy costs and agronomical implications, thus showing its impact on crop production, on soil chemical and physical properties, on weed, and on the interactions with other farming techniques.

In Italy, where this problem is compounded by the extremely high variability of climate and soil conditions, of crops and agricultural techniques, research on the possibility of reducing tillage number and depth has been considerably intensified.

In order to emphasize the present status of these studies, soil tillage has been the topic of the XIX Congress of the "Società Italiana di Agronomia (S.I.A.)", held at Viterbo (Italy) in 1985.

On that occasion the results of first two years of our trial (Rizzo et al., 1986) carried out at Foggia, on a typical environment of southern Italy, were showed. The following three-year trial period is discussed in this paper.

MATERIALS AND METHODS

Four tillage methods (A, conventional mouldboard ploughing 40-45 cm deep; B, ripper subsoiling 60-70 cm deep; C, surface disc-harrowing 15-20 cm deep; D, minimum tillage with rotary hoeing) were compared, thus interacting with four nitrogen doses (a, 0; b, 50; c, 100; d, 150 kg N ha\(^{-1}\)) on a durum wheat (cv.Isa) continuous cropping. A split-plot experimental field design with three replications was applied and tillage methods were realized on main plots of 1000 m\(^2\). Weed amount was determined on sample-areas of 33 m\(^2\), which
weren't herbicide-controlled and weeds were harvested at the end of March. For further details on the trial methodology, see above-cited paper. Data concerning the study on soil chemical and physical evolution are not discussed in this paper, owing to sake of brevity.

The trial environment is characterized by a silty clay loam soil, classified as "Typic Chromoxerert" by U.S.D.A. Soil Taxonomy (1975). It is deep and endowed with good fertility (1.46 % total N, Kjeldahl; 80 ppm absorbable P$_2$O$_5$, Olsen; 1607 ppm exchangeable K$_2$O, Schollemberg; 2.42 % organic matter, Walkey and Black).

Its climate, defined "Thermomediterranean accentuated" by UNESCO FAO maps (1960) is featured by hot-dry summers and cold-rainy winters, with considerable seasonal variations.

Rainfall recorded during the trial period from August 1984 to July 1986 (Fig.1) approached the average of the foregoing period compared (1953-82), as a whole, even though with remarkable monthly variations; in the following year (1987), on the contrary, a sharp rainfall deficit occurred, February and May excepted. Mean temperatures in the first two years of trial were higher than the ones of the foregoing period, at which those corresponded in the third year.

RESULTS

The results of the first two-year trial period, already discussed in the above mentioned paper, showed slight production rises from conventional tillage (A) to minimum one (D), thus exhibiting slight decreases as nitrogen doses increased.

The results of the following three-year trial period, including some biometrical parameters, are reported on the Table.
TABLE

Effects of tillage and nitrogen doses on wheat yield and some biometrical parameters (averages of the 1985-87 trial period) (*).

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Grain yield t ha⁻¹</th>
<th>Harvest index %</th>
<th>1000 seed weight g</th>
<th>Yellow berry %</th>
<th>Plant height cm</th>
<th>Stem density n. ha⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tillage</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>2.79a</td>
<td>31.0a</td>
<td>49.5b</td>
<td>26.2b</td>
<td>95.3a</td>
<td>410a</td>
</tr>
<tr>
<td>B</td>
<td>2.42a</td>
<td>30.5ab</td>
<td>51.1a</td>
<td>32.6a</td>
<td>90.1b</td>
<td>357c</td>
</tr>
<tr>
<td>C</td>
<td>2.45a</td>
<td>30.0ab</td>
<td>50.1ab</td>
<td>35.2a</td>
<td>89.9b</td>
<td>368b</td>
</tr>
<tr>
<td>D</td>
<td>2.47a</td>
<td>28.9b</td>
<td>45.6c</td>
<td>35.5a</td>
<td>88.0b</td>
<td>367bc</td>
</tr>
<tr>
<td>N-dose</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a</td>
<td>2.91a</td>
<td>27.6d</td>
<td>53.4a</td>
<td>44.1a</td>
<td>90.8a</td>
<td>380a</td>
</tr>
<tr>
<td>b</td>
<td>2.44b</td>
<td>28.3c</td>
<td>50.1b</td>
<td>40.5b</td>
<td>88.1b</td>
<td>361b</td>
</tr>
<tr>
<td>c</td>
<td>2.41b</td>
<td>31.4b</td>
<td>46.8c</td>
<td>23.6c</td>
<td>92.0a</td>
<td>379ab</td>
</tr>
<tr>
<td>d</td>
<td>2.33b</td>
<td>34.3a</td>
<td>45.9c</td>
<td>21.3d</td>
<td>92.3a</td>
<td>382a</td>
</tr>
</tbody>
</table>

(*) values followed by the same letters for each parameter are not significantly different at 0.05 level (Duncan's Multiple Range Test).

Grain yield seems so far scarcely influenced either by different tillage methods and by increased nitrogen doses.

Conventional tillage produced an average grain yield of about 350 kg ha⁻¹ higher than that of other methods, although the gap was not statistically significant; the zero-nitrogen test yielded 500 kg ha⁻¹ more with respect to all N-dose treatments, leading to statistical differences.

As to yields, the harvest index gradually decreased ranging from 31.0 % in treatment A to 28.9 % in treatment D and, more critically, from 34.3 % to 27.6 %, as nitrogen doses increased, showing that nitrogen rise fostered straw production rather than grain yield.

The differences in 1000 seed weight can not be easily accounted for. Minimum tillage (D) showed the lowest value, and no precise trend attributable to the kind of tillage was exhibited by all other values.

The increasing N-doses caused a gradual decrease in 1000 seed weight, up to 7.5 gap between 0 and 150 kg N treatments.

As to yellow berry percentages, nitrogen increases prompted an ample value improvement, particularly from 0 (a) and 50 (b) to 100 (c) and 150 (d) kg N, ascribable to the well-known influence played by this factor on the yellow berry. It is more interesting to notice that yellow berry tended to rise as tillage number and depth dropped, reaching the best results in conventional tillage (A), which gave the best values also in culms m⁻² and in plant height.

The interaction effects between years and experimental treatments are shown on left side of figure 2.

The variability by years prevailed over that of treatments, being particularly high between the first two years, both in normal climate conditions, and the third, when a high rainfall deficit occurred.

Barring these variations, the effects of different tillage methods on the grain yield was not affected by the seasonal climatic trend, except for
treatment A, which recorded its highest production peak in 1986.

Conventional tillage (A) also prevailed as to straw production but, in this case, on the whole trial period with a higher variability over years, reaching its highest values in 1986.

On the "year x N-doses" interaction (Fig.2), two main observations can be made: the steady depressive effect on grain yield due to nitrogen dose increases; the opposite effect on straw production, except for O-N treatment (a), which reached high values in every year of trial.

This trend was confirmed in "tillage x N-doses" interaction for any soil tillage method. Straw production increased from 50 (b) to 150 (d) kg N ha\(^{-1}\) for each tillage method. Conversely, grain yield clearly decreased as nitrogen dose increased only in conventional tillage (A).

Weed amount, represented on right side of figure 2, showed an overall and heavy effect owing to years, with a slight rises in dry matter from the first to the third year, and a large increase in green matter between the first and the following two years. In "years x tillage" interaction, each
year steadily pinpointed lower weed amounts in conventional tillage. All other treatments gave extremely variable results in the three trial years. As to "years x N-doses" interaction, that did not consider the zero-N test, the intermediate dose of 100 kg N ha\(^{-1}\) spurred a higher weed amount in 1986 and 1987, particularly in green matter amount.

At last, the interaction between the two experimental factors, tillage and N-doses, showed that results vary widely as to treatment combinations, but any clear trend can be easily observed.

DISCUSSION

The results of this research showed that in the trial environment the ploughing of conventional tillage might guarantee more or less good wheat yield increases, as against the other tillage methods compared.

In the latter, neither deep ripping, nor surface disc-harrowing improved yield with respect to rotary hoeing only of the minimum tillage. These results find partial confirmation in other research, in Italy and abroad.

Generally, ploughing led to better results, especially with reference to direct drilling (Stibbe and Karkafi, 1973; Unger, 1977; Vez, 1979; Lo Cascio e Leto, 1982; Archetti et al., 1983).

Nevertheless, a remarkable influence on tillage is played by the type of soil and by seasonal climate trend, particularly rainfall (Toderi e Bonari, 1986; Toderi et al., 1986).

Our trial, in fact, showed a great influence of seasonal rainfall on the wheat yield, which ranged from 3.2 to 1.3 t ha\(^{-1}\), on average, in 1986 and 1987 respectively, but those different conditions didn't influence the effects of treatments, which remained the same in the three years of trial.

The effects of nitrogen doses showed an decreasing production trend as N-dose rose, thus involving a better response of zero-N test during the whole trial period. This had already being found on the same environment in foregoing studies on wheat (Di Bari e Rizzo, 1979).

Furthermore, it is interesting to observe the sharp yield rise as nitrogen doses increased in conventional tillage, which paradoxically occurred thanks both to a better distribution and a more efficient N-uptake by plants.

This is an atypic situation which find few confirmation in literature.

Generally, ploughing seems to can allow less N-fertilization as against no-tillage, owing to a higher efficiency on N-uptake by plants with this method, even if a through interaction between tillage methods and nitrogen didn't stand out (Stefanovic et al., 1982; Langdale et al., 1984).

CONCLUSIONS

The comparison among four tillage methods in interaction with increasing nitrogen doses has so far shown that:

1) after an initial trend toward better wheat yields by surface and minimum tillage, the conventional moulboard ploughing began to prevail over the other tillage methods as trial years went on;

2) deep ripping, aimed at breaking soil compaction, never showed good results, nay were they worst;

3) a depressive effect on wheat yield of increasing nitrogen doses, proba
bly due to pedological and climatic troubles, so that the best yields have been obtained in zero-N test also after the fifth year of trial;
4) zero-N test gave better productive results in all the tillage methods, but the depressive effect as nitrogen doses increased were greater in mouldboard ploughing of conventional tillage;
5) a quasi-obvious lower amount of weeds in mouldboard ploughing;
6) lastly, the great climate effect on yield, connected to seasonal rainfall variability, sharply exceeded the differences recorded among the treatments.

REFERENCES


SUB-SEED INJECTION OF FERTILISERS AND PESTICIDES - EQUIPMENT AND PRELIMINARY RESULTS

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AFRC Institute of Horticultural Research, Wellesbourne, Warwick CV35 9EF
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ABSTRACT

Shallow cultivation, to no greater than seed depth, often gives better emergence of vegetable and sugar beet seedlings, because of the better supply of water through the undisturbed sub-seed zone. This zone is also the ideal target for starter fertilisers and for many soil-applied pesticides. Prototype equipment has been constructed which injects liquids into the sub-seed zone with minimal soil disturbance. Initial results indicate that the injection of starter fertiliser can produce large increases in the growth of seedlings, and that less insecticide is required when it is injected rather than applied as granules.

INTRODUCTION

In Western Europe, many crops including sugar beet, onions and early carrots are grown from seed sown directly into the soil in the field in the early spring. The yield and quality of these crops depends on the early attainment of a uniform and specific plant population and this can only be achieved by using an appropriate cultivation system. Such systems often include, in the autumn, cultivation to level the soil and the application of potassium and phosphate fertilisers. All that is then required in the spring is a very shallow cultivation and the application of a portion of the nitrogen fertiliser required by the crop, either shortly before or after drilling. The reduction in the number and depth of spring cultivations offers more opportunities to establish the crop than are available generally without preparation of the soil in autumn (Rowse and Goodman, 1984). In addition, systems of cultivation that do not extend to below seed depth have improved the speed and extent of seedling emergence because they do not disrupt the hydraulic conductivity of the soil below the seed. Consequently water is more able to move upwards towards the seed (Plake and Brinkman, 1979; Hakansson and von Polgar, 1984; Rowse et al., 1985). Eliminating the application of nitrogen fertiliser immediately before or after drilling, and replacing it with fertiliser applied from the drill, reduces the number of spring operations further. Recent work (Costigan, 1984) has indicated that placing liquid fertiliser beneath the seed increases the early growth of seedlings, even in fertile soil. However, injection of fertiliser with conventional equipment disrupts the soil beneath the seed and the benefits of shallow cultivation are negated. There is therefore a requirement for equipment to place small amounts of liquid beneath the seed with minimal soil disturbance. This paper describes the design and construction of equipment to achieve these objectives and also presents results from initial experiments using the equipment.
For the 1986 season, liquid fertiliser was pumped from a Stanhay S870 drill, using a 12 volt electric windscreen washer motor to deliver a constant 20 ml/m row at a drill speed of 3.2 kph. Application rates were achieved by dilution rather than by altering the pumping rate. The injection coulter is shown in Fig. 1. Liquid was discharged about 10 mm directly below the seed.

Fig. 1. Equipment used in 1986 to inject fertiliser and pesticide.
1 3.3 mm OD stainless steel pipe, 2 Injection coulter (3.5 mm wide), 3 Stanhay trash cutting front wheel, 4 Seed coulter.

For the 1987 season, a Stanhay S870 drill was equipped with a more versatile pumping system based on six Watson-Marlow type 303 peristaltic pumps. These pumps were ganged together on a common shaft which was driven by a 6:1 ratio chain drive directly from the land wheels of the drill. At a drilling speed of 3.2 kph the pumps were driven at 200 rpm. Table I gives the wide range of tube sizes that can be used in the pumps with the corresponding pumping rates and application rates at 3.2 kph (200 rpm).

<table>
<thead>
<tr>
<th>Tube bore (mm)</th>
<th>0.5</th>
<th>0.8</th>
<th>1.6</th>
<th>3.2</th>
<th>4.8</th>
<th>6.4</th>
<th>8.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pumping rate (ml/min)</td>
<td>6</td>
<td>14</td>
<td>54</td>
<td>200</td>
<td>440</td>
<td>720</td>
<td>1000</td>
</tr>
<tr>
<td>Application rate (ml/m row)</td>
<td>0.11</td>
<td>0.26</td>
<td>1.0</td>
<td>3.7</td>
<td>8.2</td>
<td>13.4</td>
<td>18.6</td>
</tr>
</tbody>
</table>

The equipment could be used in three configurations:

1. Constant fertiliser rate The scheme is illustrated by the solid lines in Fig. 2. Fertiliser was pumped from tank A, through the inlet manifold and out to the coulters through lines 1 to 4.
2. Constant fertiliser or diluent containing constant concentration of insecticide This is illustrated by the solid lines and dashed line through pump 5 in Fig. 2. Insecticide was pumped from tank B into the stream of fertiliser or diluent from tank A.

![Diagram of pumps and configurations](image)

Fig. 2. Arrangement of pumps for various configurations — see text for details.

3. Constant fertiliser or diluent containing a concentration of insecticide that declines logarithmically with distance. The flow of liquids is represented by all the lines in Fig. 1. In this configuration, tank B was a small vessel (typically 20 ml) which initially contained a specific volume and dilution of liquid insecticide. The bore of the tubes in lines 5 and 6 was equal so pump 6 pumped diluent into B at the same rate that pump 5 pumped diluted insecticide into the stream from tank A. A small 12 volt motor, driven from the tractor battery, was used to stir the liquid in tank B continuously.

From a theory similar to that used by Hartley et al., (1956) it may be shown that

\[ A = \frac{KC e^{-Kd/v}}{1 + f/s} \]

where

- \( A \) = dose of insecticide (g m\(^{-1}\)) at a point d(m) from the start
- \( K \) = flow rate of insecticide (g m\(^{-1}\)h\(^{-1}\))
- \( f \) = rate of flow through vessel B (ml min\(^{-1}\))
- \( S \) = speed of drill (m min\(^{-1}\))
- \( C_0 \) = initial concentration of insecticide in tank B (g ml\(^{-1}\))
- \( v \) = volume of mixing tank B (ml)

The length of pipework between tank B and the coulters delayed the insecticide concentration from decreasing logarithmically, and "run-in" to the field plots was required. The length of this run-in was determined experimentally and the results from three typical runs are shown in Fig. 3.

For the 1987 season, the injection coulter used in 1986 was replaced by a simple extension (3.5 mm wide; 10 mm deep) to the bottom of the seed coulter (Fig. 4). Liquid was pumped through a 1.3 mm diameter hole in the extension. The injection coulters used in 1986 and 1987 form part of UK Patent Application Number 86 19933.
Distance along plot (m)

Fig. 3. Measured variation in the mean dose of carbofuran with distance along plot produced by the log-dose application method.

Fig. 4. Injection coulter used in 1987 experiments. 1 Added extension, 2 Seed coulter.

EXPERIMENTS

Two identical experiments in 1986 examined the effects of sub-seed injection of nitrogen, potassium and phosphate (see Table II) on the early growth of bulb onion seedlings (cv. Rijnsburger Robusta). In autumn 1985, the soil was ploughed, 973 kg/ha of 0:20:20 fertiliser were applied and the soil was levelled. Onion seed was drilled on 10 April 1986 (expt. 1) and 13 May 1986 (expt. 2) following a light soil cultivation to about 30 mm depth. At seedling emergence, 50 kg/ha of nitrogen fertiliser was applied as a top dressing and another 50 kg about one month later. Seedlings were sampled 62 (expt. 1) and 50 (expt. 2) days after sowing and their mean fresh weight was determined for each treatment (Table II).
Table II. Mean seedling weights of onion produced by different rates of fertiliser injected under seed at drilling.

<table>
<thead>
<tr>
<th>Standard Injection</th>
<th>Injection</th>
<th>Injection</th>
<th>Injection</th>
<th>LSD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coulter + Water</td>
<td>+NPK1</td>
<td>+NPK2</td>
<td>+NPK3</td>
<td></td>
</tr>
</tbody>
</table>

- Mean fresh weight per seedling (g) -

<table>
<thead>
<tr>
<th>Expt. 1</th>
<th>Expt. 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.95</td>
<td>1.79</td>
</tr>
<tr>
<td>0.89</td>
<td>1.33</td>
</tr>
<tr>
<td>1.33</td>
<td>2.67</td>
</tr>
<tr>
<td>1.67</td>
<td>2.71</td>
</tr>
<tr>
<td>1.64</td>
<td>2.75</td>
</tr>
<tr>
<td>0.24</td>
<td>0.66</td>
</tr>
</tbody>
</table>

- Amount of element (mg/m) -

<table>
<thead>
<tr>
<th>Nitrogen</th>
<th>Potassium</th>
<th>Phosphorus</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>305</td>
<td>300</td>
<td>362</td>
</tr>
<tr>
<td>610</td>
<td>600</td>
<td>724</td>
</tr>
<tr>
<td>1220</td>
<td>1200</td>
<td>1448</td>
</tr>
</tbody>
</table>

In two experiments with radish in 1986 and 1987, the performance of the carbamate insecticide carbosulfan was evaluated against cabbage root fly. A logarithmically varying dose (Thompson et al., 1983) of a 10% active ingredient (a.i.) granular formulation was applied to the soil in both years using the bow-wave method (Makepeace, 1965) to incorporate the granules in the surface soil. The performance of the granular formulation applied conventionally in this way was compared with that of a 25% wettable powder formulation of carbosulfan applied in 1986 at 3 doses of a 25% emulsifiable concentrate formulation applied in 1987 by the log-dose system described above. Both the wettable powder and emulsifiable concentrate formulations were applied by sub-seed injection. Further details of the experiments are given by Thompson et al., (1988). The effects of the treatments on the percentage of radish undamaged by cabbage root fly are shown in Table III.

Table III. Effects of different doses of carbosulfan, applied either as granules or by sub-seed injection of liquid formulations, on the percentage of radish undamaged by cabbage root fly in 1986 and 1987.

<table>
<thead>
<tr>
<th>Method of application</th>
<th>Carbosulfan Dose (mg a.i./m row)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1986 Granules</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>26</td>
</tr>
<tr>
<td>1987 Granules</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>68</td>
</tr>
<tr>
<td></td>
<td>83</td>
</tr>
<tr>
<td></td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>95</td>
</tr>
<tr>
<td>1986 Liquid</td>
<td>40</td>
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<tr>
<td></td>
<td>82</td>
</tr>
<tr>
<td></td>
<td>92</td>
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<tr>
<td></td>
<td>98</td>
</tr>
<tr>
<td>1987 Liquid</td>
<td>70</td>
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<tr>
<td></td>
<td>89</td>
</tr>
<tr>
<td></td>
<td>96</td>
</tr>
<tr>
<td></td>
<td>99</td>
</tr>
</tbody>
</table>

RESULTS OF EXPERIMENTS AND DISCUSSION

The injection of fertiliser beneath onion seed in 1986 increased the fresh weight of onion seedlings by approximately 70% and 50% in experiments 1 and 2 respectively (Table II). These increases occurred on a fertile soil (125 µg/g K, 46 µg/g P and pH 6.7) which had received more than the recommended rates of potassium and phosphate fertiliser for an onion crop on a soil of this analysis.

In contrast with the injection of fertiliser which increased mean seedling weight, the injection of water reduced mean seedling weight (Table II). This effect observed consistently in other experiments, is
thought to be due to the physical disruption caused by the injection
coulter to the soil beneath the seed.

The protection of radish against cabbage root fly given by sub-seed
injection of carbosulfan was excellent (Table III), particularly in 1986
when the model of Phelps and Thompson, (1983) showed that a 90% reduction
in the numbers of cabbage root fly larvae was obtained with a dose of 46.3
mg a.i./m row applied as granules, but with only 21.2 mg a.i./m when the
liquid formulation was applied under seed (Thompson et al., 1988). The
differences between the methods of application were less in 1987, but they
were still in favour of the liquid treatment. The liquid injection system
also has operational advantages, as it can be used effectively in marginal
drilling conditions in moist soil when the bow-wave technique does not
work effectively.

New promising coulter designs which should cause less disruption of the
soil beneath the seed are being investigated. Provided adverse effects on
seedling establishment can be overcome, the sub-seed injection of
chemicals, possibly including fungicides also, offers an opportunity to
reduce the number of tractor operations and the amount of fertiliser and
pesticides applied to some crops.

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EFFECT OF SOIL TILLAGE AND NPK FERTILIZER DOSES ON WHEAT YIELD

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ABSTRACT

In the region of semiarid climate of Central Banat, Yugoslavia, the soil contains 60% of clay. Field experiments were performed in 1981/1982, and 1983/1984, with four variants of tillage and three variants of fertilization: a) tillage: 1) heavy disks in three passages, 2) plowing at the depth of 15 cm and 3) plowing to 30 cm and 4) subsoiling to 40 cm depth. B) fertilization: 1) control, 2) 100:80:40 and 3) 140:80:40 kg/ha NPK fertilizers.

On the basis of the obtained results, we may conclude:

- that wheat yield on all fertilization variants was higher with reduced tillage (by subsoiling, plowing at 15 cm and disking) than with conventional tillage with plowing at the depth of 30 cm.
- with the increase of the content of nitrogen fertilizers up to 140 kg/ha, wheat yield increased on all variants of the tillage.
- wheat yield much more depended on the content of nitrogen fertilizers than on depth and way of tillage.

INTRODUCTION

The increase in wheat yield per ha is a necessity from economic, strategic and social point of view. The basic soil tillage and plant nutrition are doubtless two general practises which have priority in the production process.


The aspect of content and ratio of NPK, time and method of fertilizer introduction has also a great number of investigators including (Drezgić et al, 1979), (Milojić et al, 1984), (Čurić, 1982).

WORKING METHOD

The effect of different soil tillage and the content of mineral fertilizers was studied from 1981/1982 to 1983/1984 on the chernozem type of soil with signs of gley in the loess of the region of Zrenjanin in Banat on the pre-crop of sunflower on the following variants:

A) Tillage: 1) disking (heavy) in three passages, 2) conventional plowing at 15 cm depth, 3) conventional tillage at 30 cm depth, 4) subsoiling at 40 cm depth.
B) Fertilizers: 1) control (without fertilizers), 2) 100:80:40 kg/ha NPK fertilizer, 3) 140:80:40 kg/ha NPK.
METEOROLOGICAL CONDITIONS

In the region of Banat, where field experiments were conducted, at some stages of development some climatic factors often appear, which prevent the use of wheat yield potential, as for example - the lack of moisture in autumn period during soil tillage, harvest, emergence and rooting; the occurrence of very low temperatures from the Carpathian mountains of the Alps, which sometimes destroys wheat crop and sudden occurrence of warm air masses at the period of grain forming and filling, which significantly reduces the yield of wheat.

SOIL PROPERTIES

Significant soil properties at the experimental field are given in Table 1. The soil is a heavy clay loam, since the total clay and silt content is higher than 60%. Thus, this soil belongs to a medium heavy type for tillage and seed bedding.

Table I. Texture of soil

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Coarse sand &gt;0.2 mm</th>
<th>Fine sand 0.2-0.02 mm</th>
<th>Silt 0.02-0.002 mm</th>
<th>Clay &lt;0.002 mm</th>
<th>Total sand</th>
<th>Silt and clay</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-20</td>
<td>0.60</td>
<td>39.04</td>
<td>36.44</td>
<td>23.92</td>
<td>39.64</td>
<td>60.36</td>
</tr>
<tr>
<td>20-40</td>
<td>0.00</td>
<td>36.00</td>
<td>37.28</td>
<td>26.72</td>
<td>36.00</td>
<td>64.00</td>
</tr>
<tr>
<td>40-60</td>
<td>0.00</td>
<td>32.72</td>
<td>34.96</td>
<td>32.32</td>
<td>32.72</td>
<td>67.18</td>
</tr>
</tbody>
</table>

Table II. Physical and water - air properties of soil

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Bulk density g/cm³</th>
<th>Particle density g/cm³</th>
<th>Pore space %</th>
<th>Water capacity 0.33 atm</th>
<th>Water capacity 6.25 atm</th>
<th>Water capacity 15 (wilting point) atm</th>
<th>Air capacity city</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-20</td>
<td>1.27</td>
<td>2.62</td>
<td>51.52</td>
<td>31.1</td>
<td>19.8</td>
<td>16.1</td>
<td>20.42</td>
</tr>
<tr>
<td>20-40</td>
<td>1.33</td>
<td>2.63</td>
<td>49.42</td>
<td>32.4</td>
<td>21.2</td>
<td>17.4</td>
<td>17.02</td>
</tr>
<tr>
<td>40-60</td>
<td>1.41</td>
<td>2.63</td>
<td>46.38</td>
<td>33.1</td>
<td>21.4</td>
<td>17.8</td>
<td>13.28</td>
</tr>
</tbody>
</table>

Water-physical and air properties, on the soil on which the experiment was performed are given in Table 2. The total porosity is satisfactory, especially in the layer from 0-20 cm. A rather high value of total porosity is maintained to the depth of 60 cm.
Table III. Chemical properties of soil

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>pH (H2O)</th>
<th>pH (KCl)</th>
<th>Humus %</th>
<th>P2O5 ppm</th>
<th>K2O ppm</th>
<th>B ppm</th>
<th>Mn ppm</th>
<th>Zn ppm</th>
<th>Cu ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-20</td>
<td>7.6</td>
<td>7.0</td>
<td>4.35</td>
<td>2.80</td>
<td>3.90</td>
<td>0.41</td>
<td>100</td>
<td>3.0</td>
<td>8.0</td>
</tr>
<tr>
<td>20-40</td>
<td>7.9</td>
<td>7.2</td>
<td>4.20</td>
<td>3.20</td>
<td>3.60</td>
<td>0.39</td>
<td>95</td>
<td>2.0</td>
<td>8.0</td>
</tr>
</tbody>
</table>

Chemical soil properties are given in Table 3. The soil is calcareous and neutral (in NKCl) well-provided with humus, i.e. the nitrogen content is satisfactory.

RESULTS

Wheat yield depended on the method and depth of soil tillage, NPK nutrient content and meteorological conditions (Table 4).

As far as tillage for winter wheat is concerned, the results show that the method and depth of tillage did not significantly affect wheat yield. The lowest yield in three-year investigations was obtained in the variant of tillage with plowing to 30 cm depth (5.16 t/ha) and highest in the variant with subsoiling (5.44 t/ha), i.e. 5.42% more.

In 1981/1982, the highest yield was obtained in the variant with plowing at 15 cm depth (5.7 t/ha) and lowest with plowing at 30 cm (5.59 t/ha), i.e. 7.78% less. The differences in yield in the other variants were non-significant.

In 1983/1984, the highest wheat yield, in all fertilization variants, was obtained with subsoiling (5.30 t/ha), and the lowest in the variant with plowing at 30 cm (4.90 t/ha).

In 1982/1983, in all mineral nutrient variants, the highest wheat yield was obtained with subsoiling (5.4 t/ha) and the lowest in the variant with plowing at 30 cm depth (5.01 t/ha). The variants with disking and plowing at 15 cm produced similar yields to the variant of subsoiling.

Butorac et al (1981) obtained lowest yields in first year with plowing at 30 cm depth, and with disking in the second and third year.

Konstantinović (1982) did not find significantly different depths of plowing; in 1983, he did not find differences in wheat yield within the variants of reduced and conventional tillage; in 1986 he did not find differences in wheat yields between the variants of disking and conventional tillage. Božić and Milojčić (1984) obtained a higher wheat yield with disking at 10 and plowing at 15 cm than with plowing at 25 cm.

In the agroecological conditions of Banat, very dry weather is prevalent in Autumn. In this period, more moisture evaporates from the soil than is supplied by rainfall.

Also with the conventional tillage, the soil is turned over and stays loose, which significantly intensifies the evaporation. Thus, seedbed preparation is rather difficult and large clods, up to 10 cm in diameter, prevent the placement of seeds at the optimum depth which significantly decreases the yield. Consequently, the emergence is non-uniform, lasting from 60 to 90 days. Thus, the variant of tillage by plowing to 30 cm, in three years, rendered the plowing which prevented a quality seedbed preparation.
Beside these problems, it was necessary to perform many operations within the conventional tillage which caused considerable soil compaction. It incurred additional costs for plowing without ensuring a satisfactory quality of the operation.

Table IV. Effect of soil tillage on wheat yield (t/ha)

<table>
<thead>
<tr>
<th>Year</th>
<th>Variants of tillage</th>
<th>Year of tillage</th>
<th>Doses N kg/ha</th>
<th>t/ha</th>
<th>%</th>
<th>t/ha</th>
<th>%</th>
<th>t/ha</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1981/82</td>
<td>Disking 15 cm</td>
<td>1981/82</td>
<td></td>
<td>3.60</td>
<td>100</td>
<td>6.55</td>
<td>100</td>
<td>6.82</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Plowing 15 cm</td>
<td></td>
<td>3.71</td>
<td>103.05</td>
<td>6.58</td>
<td>101.23</td>
<td>6.80</td>
<td>99.71</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Plowing 30 cm</td>
<td></td>
<td>3.50</td>
<td>97.22</td>
<td>6.53</td>
<td>100.46</td>
<td>6.75</td>
<td>98.97</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Subsoiling 40 cm</td>
<td></td>
<td>3.70</td>
<td>102.78</td>
<td>6.44</td>
<td>99.08</td>
<td>6.78</td>
<td>99.41</td>
<td></td>
</tr>
<tr>
<td>1982/83</td>
<td>Disking</td>
<td>1982/83</td>
<td></td>
<td>3.84</td>
<td>100</td>
<td>5.92</td>
<td>100</td>
<td>6.42</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Plowing 15 cm</td>
<td></td>
<td>3.95</td>
<td>102.86</td>
<td>5.84</td>
<td>98.65</td>
<td>6.38</td>
<td>99.38</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Plowing 30 cm</td>
<td></td>
<td>3.64</td>
<td>94.79</td>
<td>5.32</td>
<td>82.86</td>
<td>6.09</td>
<td>94.86</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Subsoiling 40 cm</td>
<td></td>
<td>3.95</td>
<td>102.86</td>
<td>5.90</td>
<td>99.66</td>
<td>6.33</td>
<td>98.60</td>
<td></td>
</tr>
<tr>
<td>1983/84</td>
<td>Disking</td>
<td>1983/84</td>
<td></td>
<td>3.44</td>
<td>100</td>
<td>5.87</td>
<td>100</td>
<td>6.41</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Plowing 15 cm</td>
<td></td>
<td>3.42</td>
<td>99.42</td>
<td>5.86</td>
<td>99.83</td>
<td>6.35</td>
<td>99.06</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Plowing 30 cm</td>
<td></td>
<td>3.31</td>
<td>96.22</td>
<td>5.35</td>
<td>91.14</td>
<td>6.05</td>
<td>94.38</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Subsoiling 40 cm</td>
<td></td>
<td>3.71</td>
<td>107.85</td>
<td>5.74</td>
<td>97.78</td>
<td>6.45</td>
<td>100.62</td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>Disking</td>
<td>1982/84</td>
<td></td>
<td>3.62</td>
<td>100</td>
<td>6.11</td>
<td>100</td>
<td>6.55</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Plowing 15 cm</td>
<td></td>
<td>3.69</td>
<td>101.93</td>
<td>6.09</td>
<td>99.67</td>
<td>6.51</td>
<td>99.39</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Plowing 30 cm</td>
<td></td>
<td>3.48</td>
<td>96.13</td>
<td>5.73</td>
<td>93.78</td>
<td>6.30</td>
<td>96.18</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Subsoiling 40 cm</td>
<td></td>
<td>3.79</td>
<td>104.70</td>
<td>6.02</td>
<td>98.52</td>
<td>6.52</td>
<td>99.54</td>
<td></td>
</tr>
</tbody>
</table>

In all three years, in all tillage variants, nitrogen fertilization brought significant increases in wheat yield. In the first year of the experiment, this increase, as compared with the control, was 83.24 to 92.86%. In the second year, yield increases were somewhat lower, but still highly significant in relation to the control. In all three years of investigation, the highest wheat yield was obtained with the highest nitrogen dose of 140 kg/ha/N, while wheat yield in the variants with 100 kg/ha/N was significantly lower. Thus, it was concluded that 140 kg/ha/N is the optimum dose for these agroecological conditions. A specially favourable effect of an increased content of nitrogen fertilizer on wheat yield was obtained by Cvetković and Stojanović (1982). Spasojević and Malešević (1986) and Bogdanović (1985) obtained the highest yield in the variant with 120 kg/ha/N.

On the three year average (1981/1984) the highest wheat yield was obtained by the highest nitrogen dose of 140 kg/ha. The difference in wheat yield between 140 and 100 kg/ha/N ranged from 0.42 to 0.56 t/ha of grain in favour of the larger dose.
CONCLUSION

Reduced and rational soil tillage provide quality seedbed preparation and wheat sowing, as well as significant savings in fuel, manpower and machines. At the same time, profitability of production is increased.

When introducing a rational system of wheat fertilization, it is necessary to take care about soil type, climate, weather conditions, previous crop, soil moisture content, harvest residues, physical properties of soil, plot size and position, and agricultural machinery available.

Our experiments show that wheat yields in all fertilization variants, were higher with reduced tillage than with conventional tillage.

The yield of winter wheat increased in proportion with the increase of nitrogen fertilizer. The highest yield was obtained with 140:80:40 kg/ha NPK.

The yield of winter wheat depended more on the content of nitrogen fertilizer, with adequate doses of P and K, than on the method of soil tillage.

LITERATURE

RESIDUAL EFFECT OF CHISELLING ON GROWTH AND WATER STATUS OF RAINFED SOYBEANS

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Bihar, Pusa - 848 125 (India)
²Mingano Agricultural Research Institute, Tanzanian Agricultural Research Organization, Private Bag Ngomeni, Tanga (Tanzania)

ABSTRACT

One year after deep chiselling (58-60 cm depth), its residual effect was investigated on plant water relations and growth of rainfed soybeans (Glycine max (L.) Merr.) on a sandy loam Alfisol soil having a high bulk density layer at 14-28 cm depth. Measurements were made for bulk density of soil, leaf water potential, leaf area, plant height, shoot dry weight, number of secondary roots, thousand grain weight and the grain yield of soybeans. Bulk density of 14-28 cm layer and layers below it up to 60 cm depth was significantly (p<0.05) lower in chiselled plots. Leaf water potential, leaf area, plant height, and shoot dry weight were higher (p<0.05 or 0.01) in chiselled plots. However, the number of secondary roots was higher in conventionally ploughed plots. Thousand grain weight and grain yield were significantly (p<0.01) higher for chiselled than for conventionally ploughed plots. Thus, the residual effect of chiselling was still persisting one year later.

INTRODUCTION

Presence of subsoil layers of high bulk density in soils usually results in yield reductions of crops (Mussick and Dusek, 1975). These yield reductions due to increased bulk density vary with location, season, soil type and the type of crop. In the tropics, the situation is aggravated by unreliable and poorly distributed rainfall as well as by generally low water holding capacity of the tropical soils (Hsiao, 1973). Many soils in Tanzania are reported to have compacted subsoil layers of 10 to 15 cm thickness (Rwehumbiza, 1983; Sharma, 1986).

Subsoiling may not be considered to be a current tillage operation, but it could be used to improve the plant growth environment in those soils that have impervious layers formed either from plough-layer pan formation or surface compaction. However, because of high cost of chiselling and excessive compaction that may be caused by heavy machinery or animal traffic, subsoiling can only be repeated every few years. It is therefore, essential to know as to for how long the effect of subsoiling lasts on a particular type of soil. Information on this aspect for Alfisols is lacking. In view of this, present experiment was carried out to assess the residual effect of chiselling a sandy loam Alfisol after a lapse of one year time which corresponds to the third consecutive growing season.
METHODS

A field of sandy loam (83.2 and 15% sand, silt and clay, respectively) Alfisol having a high bulk density (1.72 Mg m\(^{-3}\)) layer at 14-28 cm depth at the Horticultural unit of the Sokoine University of Agriculture Morogoro, Tanzania was divided into two blocks. One block was chiselled to a depth of 58-60 cm using a heavy duty subsoiler with chisels fixed half a meter apart. Both blocks were then conventionally ploughed to 12 cm depth using a moldboard plough drawn by a garden tractor and seeded with maize. One year later both the blocks were only conventionally ploughed and seeded with soybeans (Glycine max (L.) Merr.). Residual chiselling (hereafter, chiselling) was considered as one tillage method and the conventional ploughing as the other.

Four treatment combinations consisting of two methods of tillage and two soybean cultivars viz., Glycine max (L.) Merr. cv. Bossier and cv. C 51 were replicated five times in a split plot experiment in the plot size of 3x3 m with a headland of 0.5 m within and between blocks taking tillage methods as main and soybean cultivar as sub-plots. Soybean which was grown as a rainfed crop was manually seeded at 5 cm within and 60 cm between rows on February 14, 1986. Total rainfall from 1 day before seeding until 1 week before harvesting amounted to 422.5 mm.

To ascertain residual effect of chiselling on plant water status and growth of soybeans, leaf water potential, leaf area, plant height, shoot dry weight and number of secondary roots (thicker than 1 mm diameter) located within top 14 cm depth were measured at various stages during crop growth on 4 plants from each treatment plot at every stage of observation. Thousand grain weight and the grain yield were recorded after harvest at 97 days after planting (DAP).

Leaf water potential was measured between 1300 to 1400 h on a fully grown and exposed fourth leaf from the tip on the main branch using pressure bomb technique (Boyer, 1967). A digital type pressure bomb (Model: ARIMAD-2, Israel) was used. Leaf area was measured using an electronic planimeter (Model: Paton, Australia). For shoot dry weight samples were dried in an oven at 68°C for 48 hours before recording their weights. Number of secondary roots per plant were recorded by digging plant root system up to 14 cm depth. Soil bulk density was measured after harvesting using undisturbed cores.

RESULTS

The soil bulk density (Table I) in 0-14 cm depth was not affected by the tillage methods. However, in the subsoil layers up to 60 cm depth, the bulk density was significantly (p<0.05) lower in chiselled than in conventionally ploughed plots.

Leaf water potential (Table II) of both cultivars at various stages of growth was significantly (p<0.05) higher.
Table I

Bulk density (Mg m\(^{-3}\)) of various soil layers at the harvest of soybean as affected by the tillage methods

<table>
<thead>
<tr>
<th>Soil depth (cm)</th>
<th>Tillage method</th>
<th>F test/LSD (0.05)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Conventional</td>
<td>Chisel</td>
</tr>
<tr>
<td>0-14</td>
<td>1.63</td>
<td>1.60</td>
</tr>
<tr>
<td>14-28</td>
<td>1.72</td>
<td>1.59</td>
</tr>
<tr>
<td>28-43</td>
<td>1.63</td>
<td>1.56</td>
</tr>
<tr>
<td>43-60</td>
<td>1.66</td>
<td>1.53</td>
</tr>
</tbody>
</table>

NS = not significant

Table II

Leaf water potential (-MPa) of soybean cultivars as affected by tillage methods

<table>
<thead>
<tr>
<th>Days after plant</th>
<th>Cultivar</th>
<th>Tillage method</th>
<th>F test/LSD (0.05)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Conventional</td>
<td>Chisel</td>
</tr>
<tr>
<td>35</td>
<td>Bossier</td>
<td>1.31</td>
<td>1.14</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.24</td>
<td>1.17</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>1.27</td>
</tr>
<tr>
<td></td>
<td>LSD(0.05)</td>
<td>0.08</td>
<td></td>
</tr>
<tr>
<td>46</td>
<td>Bossier</td>
<td>0.72</td>
<td>0.58</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.79</td>
<td>0.71</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>0.75</td>
</tr>
<tr>
<td></td>
<td>LSD(0.05)</td>
<td>0.06</td>
<td></td>
</tr>
<tr>
<td>74</td>
<td>Bossier</td>
<td>0.69</td>
<td>0.65</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.68</td>
<td>0.59</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>0.68</td>
</tr>
<tr>
<td></td>
<td>LSD(0.05)</td>
<td>0.03</td>
<td></td>
</tr>
</tbody>
</table>

NS = not significant

under chiselling than under conventional ploughing. At 46 and 74 DAP cultivars also showed significant (p<0.05) differences but lacked consistent trend. Whereas at 46 DAP, Bossier showed a higher leaf water potential, it was C 51 which showed higher potential at 74 DAP.

Data on leaf area per plant, plant height and shoot dry weight per plant are presented in Table III. Leaf area for both the cultivars was significantly (p<0.05 at 42 DAP; p<0.01 at 74 DAP) higher in chiselled than in conventionally ploughed plots. At 74 DAP, both cultivars in conventionally ploughed plots showed a lower leaf area (819 cm\(^2\)) compared to that at 42 DAP (935 cm\(^2\)). In chiselled plots however, leaf area at 74 DAP was greater than that at 42 DAP. Plants growing in chiselled plots were significantly (p<0.01 at 63 DAP; p<0.05 at 84 DAP) taller than those in conventionally ploughed plots. Plant height at 84 DAP in chiselled plots was 64.3 cm as against 56.3 in conventionally ploughed plots. Shoot dry weight (Table III) was also affected significantly
by the tillage methods. Plants in chiselled plots produced significantly higher shoot dry weight per plant than those in conventionally ploughed plots.

Table III

Effect of tillage methods on leaf area, plant height and shoot dry weight of soybean cultivars

<table>
<thead>
<tr>
<th>Growth parameter</th>
<th>Days after planting</th>
<th>Cultivar</th>
<th>Tillage method</th>
<th>Mean</th>
<th>F test/ LSD (0.05)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leaf area (cm² plant⁻¹)</td>
<td>42</td>
<td>Bossier</td>
<td>Conventional</td>
<td>973</td>
<td>1614</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C 51</td>
<td>Conventional</td>
<td>897</td>
<td>1607</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td></td>
<td>935</td>
<td>1624</td>
</tr>
<tr>
<td></td>
<td>74</td>
<td>Bossier</td>
<td>Conventional</td>
<td>798</td>
<td>2042</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C 51</td>
<td>Conventional</td>
<td>841</td>
<td>1753</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td></td>
<td>819</td>
<td>1897</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LSD (0.01)</td>
<td></td>
<td>654</td>
<td></td>
</tr>
<tr>
<td>Plant height (cm)</td>
<td>63</td>
<td>Bossier</td>
<td>Conventional</td>
<td>41.3</td>
<td>51.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C 51</td>
<td>Conventional</td>
<td>41.0</td>
<td>50.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td></td>
<td>41.15</td>
<td>50.70</td>
</tr>
<tr>
<td></td>
<td>84</td>
<td>Bossier</td>
<td>Conventional</td>
<td>56.5</td>
<td>63.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C 51</td>
<td>Conventional</td>
<td>56.2</td>
<td>65.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td></td>
<td>56.35</td>
<td>64.35</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LSD (0.05)</td>
<td></td>
<td>5.60</td>
<td></td>
</tr>
<tr>
<td>Shoot dry weight (g plant⁻¹)</td>
<td>42</td>
<td>Bossier</td>
<td>Conventional</td>
<td>4.3</td>
<td>6.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C 51</td>
<td>Conventional</td>
<td>4.7</td>
<td>5.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td></td>
<td>4.50</td>
<td>6.00</td>
</tr>
<tr>
<td></td>
<td>63</td>
<td>Bossier</td>
<td>Conventional</td>
<td>8.2</td>
<td>10.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C 51</td>
<td>Conventional</td>
<td>6.6</td>
<td>9.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td></td>
<td>7.40</td>
<td>10.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LSD (0.01)</td>
<td></td>
<td>1.38</td>
<td></td>
</tr>
</tbody>
</table>

NS = not significant

Table IV

Effect of tillage methods on the number of secondary roots (number plant⁻¹), thicker than 1 mm, in 0-14 cm depth for soybean cultivars

<table>
<thead>
<tr>
<th>Days after planting</th>
<th>Cultivar</th>
<th>Tillage method</th>
<th>Conventional</th>
<th>Chisel</th>
<th>Mean</th>
<th>F test</th>
</tr>
</thead>
<tbody>
<tr>
<td>63</td>
<td>Bossier</td>
<td>20.4</td>
<td>14.8</td>
<td>17.60</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C 51</td>
<td>21.0</td>
<td>14.4</td>
<td>17.70</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>20.70</td>
<td>14.60</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>LSD (0.01)</td>
<td>3.62</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>84</td>
<td>Bossier</td>
<td>30.0</td>
<td>26.8</td>
<td>28.40</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C 51</td>
<td>31.4</td>
<td>26.0</td>
<td>28.70</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>30.70</td>
<td>26.40</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>LSD (0.01)</td>
<td>3.72</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NS = not significant
Table V
Effect of tillage methods on 1000 grain weight (g) of soybean cultivars

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Tillage method</th>
<th>Mean</th>
<th>F test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Conventional</td>
<td>Chisel</td>
<td></td>
</tr>
<tr>
<td>Bossier</td>
<td>120.9</td>
<td>145.7</td>
<td>133.30</td>
</tr>
<tr>
<td>51</td>
<td>122.1</td>
<td>140.9</td>
<td>131.50</td>
</tr>
<tr>
<td>Mean</td>
<td>121.50</td>
<td>143.30</td>
<td></td>
</tr>
<tr>
<td>LSD(0.05)</td>
<td></td>
<td>13.30</td>
<td></td>
</tr>
</tbody>
</table>

NS = not significant

Table VI
Grain yield (Mg ha⁻¹) of soybean cultivars as affected by tillage methods

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Tillage methods</th>
<th>Mean</th>
<th>F test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Conventional</td>
<td>Chisel</td>
<td></td>
</tr>
<tr>
<td>Bossier</td>
<td>2.79</td>
<td>4.97</td>
<td>3.88</td>
</tr>
<tr>
<td>51</td>
<td>3.25</td>
<td>4.64</td>
<td>3.94</td>
</tr>
<tr>
<td>Mean</td>
<td>3.02</td>
<td>4.80</td>
<td></td>
</tr>
<tr>
<td>LSD(0.01)</td>
<td></td>
<td>0.395</td>
<td></td>
</tr>
</tbody>
</table>

NS = not significant

The number of secondary roots per plant (Table IV) within top 14 cm soil depth at 63 and 84 DAP were significantly (p<0.01) higher in conventionally ploughed than those in chiselled plots.

Weight of 1000 seeds (Table V) and grain yield (Table VI) from chiselled plots were significantly (p<0.01) higher than that from the conventionally ploughed plots. Averaging over both cultivars, grain yield from chiselled plots was about 1.6 times higher than that from conventionally ploughed plots.

DISCUSSION

Lack of significant differences in the soil bulk density of 0-14 cm layer between chiselled and conventionally ploughed plots suggests that chiselling had no additional effect in reducing the bulk density of surface layer. This conforms to the findings of other workers (Chaudhary et al., 1985 and Sharma, 1986). On the other hand, because of working-up of soil by chisels down to 58-60 cm depth, significantly (p<0.05) lower bulk densities acquired by the deeper soil layers between 14 to 60 cm depth in chiselled than in conventionally ploughed plots (Sharma, 1986), were still persisting one year after chiselling. Residual effect of subsoiling has been reported even after 2 years (Busscher et al., 1986).

Significantly higher leaf water potential of plants under chiselled than that under conventionally ploughed plots indicated favourable conditions for water extraction in chiselled plots (Hobbs et al., 1961; Sharma, 1986). Considerable reduction in the bulk density of 14-28 cm layer
and that of layers below might have helped plant roots in chiselled plots penetrate deeper (Musick and Dusek, 1975) and exploit subsoil moisture more effectively. Greater number of secondary roots on plants in conventionally ploughed plots indicates that plants were forced to generate more number of roots to meet demands from within top soil layer. Thus a better plant growth as well as significantly higher grain yield in chiselled plots could be attributed to a better plant growth environment in these plots (Boyer, 1970).

CONCLUSIONS

It is concluded that the residual effect of chiselling was still persisting up to third consecutive growing season.

REFERENCE

MECHANISMS BY WHICH STRAW RESIDUES CAN LIMIT THE USE OF SIMPLIFIED TILLAGE FOR WINTER WHEAT

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ABSTRACT

In both laboratory and field experiments straw residues from the previous crop affected the vegetative growth of winter wheat but the magnitude of effects was greater in a clay soil than in a sandy loam. Residues left on the soil surface reduced emergence more than if the straw was incorporated but this was not because temperature at seeding depth was significantly lower. Nitrogen added to the straw overcame effects where straw was incorporated but not where it was on the soil surface. Leaf length, plant weight and tiller production were all reduced by the presence of straw but much of this was associated with competition for nitrogen between plants and those microbes breaking down the straw. A small part of the effect was most likely to have been caused by toxins produced aerobically during breakdown. Effects of straw on grain yield were less than those on vegetative growth but resulted mostly from the production of fewer fertile ears.

INTRODUCTION

Crop residues are a major constraint to the development of simplified tillage systems in the UK (Goss et al., 1988). The presence of straw on the soil surface can interfere with the action of drills and prevent even distribution of seed within the drill rows (Oliphant, 1982). Slug damage can increase if drill slits remain open (Christian et al., 1988). There is a greater risk from the carry-over of disease (Christian and Miller, 1984) and poor crop growth in the presence of straw has been attributed to the production of phytotoxins (Lynch, 1977). Incorporation of straw with a large C/N ratio inevitably immobilizes some mineral nitrogen during decomposition (Parr and Papendick, 1978). Straw will also act as a mulch and tend to lower soil temperatures, change the soil water regime and dependant aeration status (Van Dorren and Allmaras, 1978). However, the relative importance of these different factors in restricting crop yields has not been evaluated so that remedial treatments can be developed.

In this paper the timing of effects of straw residues on crop growth is investigated and the importance of phytotoxins and nitrogen immobilization are assessed.

METHODS

Experiments were carried out on a clay soil (Lawford series) and a sandy soil (Lowland series), both in the field and in pots under controlled environments. These soils were chosen because long-term
experiments to investigate methods of straw disposal had already been established on them. In addition, contrasts in texture and organic matter (Table I) could be exploited to gain an insight into mechanisms affecting plant growth. Wheat was grown as the test crop throughout. In field experiments, straw from the previous crop was used and so the weight varied between seasons. In the laboratory experiments the equivalent of 20 t ha\(^{-1}\) straw (chop size 10 mm) was used which, when incorporated in a 100 mm layer, gave a concentration of 2% by weight. Controls were plots where crop residues were burnt and pots where no straw was added to the soil.

**TABLE I. Summary of properties for the experimental soils**

<table>
<thead>
<tr>
<th>Soil series</th>
<th>Particle size distribution (% w/w)</th>
<th>Organic carbon (% w/w)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sand (60μm-2mm)</td>
<td>Silt (2-60μm)</td>
</tr>
<tr>
<td>Lawford</td>
<td>21.0</td>
<td>40.0</td>
</tr>
<tr>
<td>Lowland</td>
<td>77.0</td>
<td>12.6</td>
</tr>
</tbody>
</table>

**RESULTS**

In the field, volunteer plants made it difficult to identify effects of straw on emergence, especially with shallow incorporation. However, fewer plants tended to establish on direct-drilled plots where straw was burnt. In laboratory experiments the presence of straw on the soil surface delayed the time for 50% emergence by 2.4 days for Lowland soil and 3.9 days on Lawford soil (Table II). Straw on the soil surface reduced final plant numbers by about 20% on the Lawford soil. Where straw was incorporated the application of nitrogen overcame the delay in emergence on the Lawford soil and on both soils final plant numbers were unaffected.

**TABLE II. Effect of straw and nitrogen on the time (days) to 50% emergence on two soils.**

<table>
<thead>
<tr>
<th>Straw distribution</th>
<th>Nitrogen(^1)</th>
<th>Soil series</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Lawford</td>
<td>Lowland</td>
<td></td>
</tr>
<tr>
<td>Nil (control)</td>
<td>-N</td>
<td>5.9</td>
<td>4.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>+N</td>
<td>6.2</td>
<td>6.0</td>
<td></td>
</tr>
<tr>
<td>Mixed</td>
<td>-N</td>
<td>7.1</td>
<td>5.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>+N</td>
<td>5.6</td>
<td>5.0</td>
<td></td>
</tr>
<tr>
<td>Surface</td>
<td>-N</td>
<td>8.1</td>
<td>7.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>+N</td>
<td>10.1</td>
<td>7.2</td>
<td></td>
</tr>
</tbody>
</table>

\(^{1}\) 1.122 g nitrogen fertilizer added to the straw in the +N pots to reduce the C/N ratio from 80 to 20.

In pots, incorporating straw significantly reduced plant dry weight at 40 days after planting on both soils unless nitrogen was applied (Table III). There was no effect of incorporating straw on shoot growth and
development in the field experiment on the Lowland soil. On the clayey
textured Lawford soil both shoot numbers and plant dry weight were
reduced by straw though effects were greater where the straw was left on
the surface and the crop direct-drilled than where straw was incor-
porated.

TABLE III. Effect of straw and nitrogen on plant dry weight at 40
days after planting in Lawford and Lowland series soil.

<table>
<thead>
<tr>
<th>Nitrogen¹</th>
<th>Straw distribution</th>
<th>Plant dry weight (mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N0 (control)</td>
<td>Mixed</td>
<td>238</td>
</tr>
<tr>
<td>N0 (control)</td>
<td>Surface</td>
<td>132</td>
</tr>
<tr>
<td>N0 (control)</td>
<td>Surface</td>
<td>257</td>
</tr>
</tbody>
</table>

¹ 1.222 g nitrogen fertilizer added to the straw in the +N pots to reduce the C/N ratio from 80 to 20.

In pot experiments straw left on the surface reduced the length of leaves 3 and 4 on the mainstem. When straw was incorporated the length of leaves 1-4 was reduced by at least 14%. Addition of nitrogen could not overcome the effects of straw on the elongation of leaves 3 and 4. The concentration of straw modified the magnitude of the effects on leaf length and tillering (Table IV). In contrast to the other leaves, the length of the flag leaf was increased by straw.

TABLE IV. Effect of straw content and the application of foliar nitro-
gen on leaf length 32 days after sowing. Lawford series soil.

<table>
<thead>
<tr>
<th>Straw content (% w/w)</th>
<th>Leaf length (mm)</th>
<th>Tillers/plant</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Leaf 1</td>
<td>Leaf 2</td>
</tr>
<tr>
<td>0 (control)</td>
<td>110</td>
<td>135</td>
</tr>
<tr>
<td>0.5</td>
<td>110</td>
<td>136</td>
</tr>
<tr>
<td>1.0</td>
<td>106</td>
<td>127</td>
</tr>
<tr>
<td>2.0</td>
<td>99</td>
<td>119</td>
</tr>
<tr>
<td>sed</td>
<td>2.5</td>
<td>3.9</td>
</tr>
<tr>
<td>-Foliar N</td>
<td>103</td>
<td>126</td>
</tr>
<tr>
<td>+Foliar N¹</td>
<td>108</td>
<td>133</td>
</tr>
<tr>
<td>sed</td>
<td>1.8</td>
<td>2.8</td>
</tr>
</tbody>
</table>

¹ Nitrogen as 0.1M urea solution painted onto leaves daily.

Tiller production was delayed by the presence of straw but the applica-
tion of nitrogen overcame the effects in the Lowland soil and markedly
decreased them in the Lawford soil. In the field the delay in tillering
where straw was retained on the soil surface of the Lawford soil reduced
the number of plants that had tillers above the second shoot node, and those plants with secondary tillers at the end of winter. By late spring the presence of straw on the soil surface no longer impaired tiller production and the loss of tillers after maximum numbers were reached averaged only 1.5 per plant where straw was retained compared with 3 per plant where straw was removed. Thus the number of fertile high-order tillers was greater where straw was retained but the total number of shoots was less than after burning.

Grain yield was impaired by 42% when straw was left on the surface of the Lawford soil under field conditions but the effect of straw was not statistically significant in experiments under controlled environments (P>0.05). Where straw was incorporated in the laboratory, yields were reduced on both Lawford and Lowland soils, but an application of nitrogen with the straw largely overcame the effect. Under field conditions the effect of straw residues on grain yield in Lawford soil decreased the deeper the straw was incorporated (15% when incorporated to 50 mm and less than 2% when incorporated to 150 mm).

The effects of straw on grain yield largely resulted from differences in the number of fertile ears in both the laboratory and the direct-drilled crop in the field. However, straw also affected the number of grains per ear in the laboratory and the field in 1985 and grain weight in 1986. Reductions in fertile ear number by straw can be compensated for by increases in another component such as number of grains per ear (Table V).

| Table V. Effect of straw on the number of grains per ear according to the origin of the ear. |
|---------------------------------|----------------|----------------|------|
| Origin of ear                  | Grain number  | Burnt          | Retained on surface | sed |
| Main stem                      | 47.4          | 45.9           | 5.80             |
| 1st tiller                     | 46.0          | 50.1           | 5.01             |
| 2nd tiller                     | 41.7          | 48.7           | 5.48             |
| 3rd tiller                     | 30.7          | 45.8           | 4.15             |
| Others                         | 6.2           | 11.2           | 4.53             |

The consequences of straw incorporation on soil aeration were investigated in the Lawford soil because there straw had greater effects on growth because clay soils are usually poorly permeable. The soil was kept at 10°C during the experiment, typical for autumn conditions in England. Despite the soil being maintained at a constant potential of −2 kPa, the redox potential in the middle of a 100 mm layer of 2% straw was maintained at +590 mV compared with +600 mV at the same depth without straw. The oxygen concentration was reduced to about 16% and the concentration of carbon dioxide increased to about 1% in the straw layer compared with 22% oxygen and 0.1% carbon dioxide in controls. When pre-germinated seeds were sown in the soil this further affected aeration status but only to give small increases in the CO₂ concentration in the presence or absence of straw. Shoot growth was adversely affected by the presence of straw under these conditions as was shoot:root ratio because root growth was slightly increased (Table VI). However, separating the
seed from the mixed soil and straw layer by only 25 mm was beneficial to growth.

**TABLE VI. Effect of straw and the position of seeding on plant dry weight and root growth 23 days after sowing Lawford series soil.**

<table>
<thead>
<tr>
<th>Plant weight (mg)</th>
<th>Shoot:root ratio</th>
<th>Root length (cm/pot)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Shoot</td>
<td>Root</td>
</tr>
<tr>
<td>Controls</td>
<td>31.1</td>
<td>14.7</td>
</tr>
<tr>
<td>Seed on straw</td>
<td>25.1</td>
<td>17.0</td>
</tr>
<tr>
<td>Seed 25mm above straw</td>
<td>29.7</td>
<td>17.3</td>
</tr>
<tr>
<td>seed</td>
<td>1.80</td>
<td>1.35</td>
</tr>
</tbody>
</table>

In the laboratory experiments it was possible to investigate the breakdown of the straw and the effects on mineral nitrogen in the soil. The greater the concentration of straw the more nitrogen was immobilized by the straw but at the same time less straw was broken down by the microbial activity (Table VII).

**TABLE VII. Effect of straw concentration on straw weight loss and the reduction in soil nitrate.**

<table>
<thead>
<tr>
<th>Straw concentration</th>
<th>Weight loss (% w/w)</th>
<th>Reduction in soil nitrate (µg g⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5%</td>
<td>51.4</td>
<td>27</td>
</tr>
<tr>
<td>1.0</td>
<td>45.4</td>
<td>41</td>
</tr>
<tr>
<td>2.0</td>
<td>38.1</td>
<td>51</td>
</tr>
</tbody>
</table>

In the field the effect of straw on soil temperature was studied on the Lawford series soil. In winter, where straw covered the ground it was warmer at the soil surface compared with plots where straw had been burnt. However, the temperature at the surface of the straw was cooler than the soil surface where straw was burnt, during periods of frost. Generally the lower the night minimum the greater the difference and the temperature on top of the straw was up to 8°C cooler than the soil surface of burnt plots. Conversely during early spring, temperatures beneath surface straw were cooler than where straw had been burnt. Incorporated straw had only a very small effect on soil temperature. Mean daily temperatures during March to April were about 4°C cooler where straw had been incorporated to 50 mm.

Total accumulated thermal time measured in the soil at 25 mm between 3 December 1986 and 22 April 1987, was similar whether straw was left on the surface, incorporated to 150 mm or burnt. However, less thermal time accumulated (approximately 20 day degrees above 0°C) when the straw was incorporated to only 50 mm.)
DISCUSSION

The results from both laboratory and field experiments showed that straw residues from the previous crop affected the growth and development of winter wheat at the time of seedling emergence and all through vegetative growth. Both leaf extension and tillering were adversely affected by straw. Differences in soil temperatures were not correlated with differences in shoot growth where straw was left on the soil surface. At about the time of stem elongation, crops affected by straw showed compensatory growth so differences in plant growth became smaller. Grain yield was not necessarily reduced by the presence of straw but any differences were mostly due to production of fewer fertile ears and fewer grains per ear.

At 10°C, even the incorporation of 20 t ha\(^{-1}\) straw did not result in anaerobiosis of soil kept at a matric potential of -2 kPa. Therefore, the suggestion that the poor growth in the presence of straw was caused by products of microbial decay such as acetic acid was not supported by our findings as they require anaerobic conditions.

The reduction of the shoot:root ratio in the presence of straw was consistent with plant growth being constrained by nitrogen supply. The fact that even under controlled environments nitrogen applications did not fully overcome all adverse effects of straw suggests that some may have been caused by aerobically produced toxins but we have no idea of their chemical identity.

REFERENCES

MULCH-SEED TECHNIQUES FOR CONSERVATION TILLAGE IN THE FEDERAL REPUBLIC OF GERMANY

C. SOMMER, M. DAMBROTH and M. ZACH

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ABSTRACT

Tillage and planting equipment for conventional tillage systems was developed to operate with no crop residues on or near the soil surface and on a relatively smooth soil surface. Conservation tillage requires implements that can be operated in rough residue-covered soils. Recently, modifications and new types of machines have been developed to achieve functional requirements for conservation tillage.

INTRODUCTION

Conservation tillage is a relatively new concept in the F. R. Germany. The fundamental ideas of this concept are (Sommer et al., 1981):

1. An efficient possibility to reduce or prevent soil erosion is to minimize soil tillage intensity and

2. to leave sufficient amounts of residues on or near the soil surface.

Unquestionably the most effective way of reducing erosion is to have living or dead vegetation on the soil surface.

One of the obstacles to adoption of conservation tillage systems was the lack of implements suitable for conservation tillage and planting (Sommer et Lindstrom, 1987). But today, conventional planters have been adapted to conservation tillage systems or new equipment has been developed. Problems, for the most part, have been solved and today farmers have a wide variety of excellent planters for "mulch-seeding without seedbed preparation" or "mulch-seeding with seedbed preparation" (Sommer et al., 1987).

METHODS

Planting equipment available in Germany is not specifically designed for conservation tillage and must be modified for best performance in surface residues. Mulch planters or drills must cut and clear residue and provide uniform soil penetration, and seed placement under different conditions of surface mulch.
Technical solutions to this problem that are presently used in Germany are depicted in Fig. 1.

With no-till planting ('mulch-seeding without seedbed preparation'), seed is planting in undisturbed soil. The soil is covered with residues or sod, and is most likely wetter, firmer and possibly rougher. There are three main possibilities:

1. One that can clear a more or less small band from residues in front of each planter unit by using two vertical row clearing discs (Fig. 1 a) followed by conventional planter units, Fig. 2. Sometimes an additional fluted coulter is following the double discs to provide a narrow band of tilled soil.

Fig. 1: Technical solutions being investigated in Germany for manipulation of crop residues with planting in conservation tillage systems

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Fig. 2: Conservation tillage planter for row crops as sugar beets or maize (System Becker)
2. A different design is to cut through previous crop residues or sod without excessive problems, Fig. 3.

![Fig. 3: Conservation tillage planter for row crops as sugar beets or maize (System Kleine)](image)

3. Another possibility is a technical solution which is up to now available as a prototype (Brinkmann, 1983). A seed tube is pressed into the depth of seed placement (Fig. 1 b) and a seed piston is pushing the seed through the seed tube at the preselected uniform depth, Fig. 4. High amounts of residues on the soil surface do not cause any problems.

![Fig. 4: A special conservation tillage planter (System Landtechnik Bonn)](image)

With mulch-till planting ('mulch-seeding with seedbed prep-
ration'), seed is planting in a soil-residue mixture. Under most conditions the conventional planters for row crops and drills for small grain, as well, will function.

A special air seeder technique is available which consists of a rotary tiller followed by a horizontal seed tube. Seed is placed on undisturbed soil and covered by a soil-residue mixture, Fig. 5.

Fig. 5: A special conservation tillage drill technique
(System Horsch)

The German concept of conservation tillage allows for soil loosening by noninversion tillage before establishment of a winter cover crop following winter barley. At this time mostly the soil is dry and the effect of soil loosening is good. The combination of soil loosening, seedbed preparation and drilling winter cover crop allows a crop establishment without tracks, Fig. 6. The mechanically improved soil structure will be stabilized by the growing roots of the cover crop. That means a better trafficability in the following spring time when sugar-beets are planted.
Fig. 6: Soil loosening, seedbed preparation and drilling in one operation. Different drill units are available which allow seed placement before or behind the back roller.

CONCLUSION

A wide variety of equipment is now available to aid the conservation tillage farmer. Manufacturers continue to introduce new tools as the trend towards reduced tillage grows.

REFERENCES


THE MULCH-SEED CONCEPT AS A PART OF CONSERVATION TILLAGE AND INTEGRATED CROP PRODUCTION

C. SOMMER, M. DAMBROTH and M. ZACH

Institute of Crop Science and Plant Breeding, Federal Agricultural Research Centre Braunschweig-Völkenrode (FAL) (F. R. Germany)

ABSTRACT

Reducing soil tillage intensity and leaving crop residues on or near the soil surface are the basic ideas of conservation tillage. Nowadays the development of effective conservation tillage systems is a research field in the Federal Republic of Germany. Meanwhile more and more farmers trying conservation tillage for the first time on a small-scale to learn controlling excessive erosion in a cost-effective manner. Yet we also have a number of farms where the use of conservation tillage is widespread. Many modifications have been made to improve the performance of equipment for conservation tillage and some new types of machines have been developed, as well. The paper presents some remarks and results of the essential part 'mulch-seed' of the conservation tillage system for row crops and cereals which was developed for German conditions by the Institute of Crop Science and Plant Breeding at Braunschweig-Völkenrode.

INTRODUCTION

Conservation tillage is a relatively new management concept in the F. R. Germany. Impetus for conversion to conservation tillage systems comes from the federal Government and is based on observations of soil degradation either from soil erosion or soil compaction.

Much of the agricultural production in Germany is based on narrow crop rotation of small grain and root crops. Present tillage management systems are intensive and are based on primary cultivation with deep loosening, seedbed preparation and stubble mulching. The farmer's aim is to produce and maintain a loose soil by ploughing once or twice every year to full depth of the arable layer (25 - 35 cm depth). This plus harvest and crop transport traffic has resulted in a breakdown of natural soil structure increasing soil susceptibility to soil compaction and soil erosion.

The degree of intensity of tillage has significant effects on the amount of surface cover: the more intensive the tillage, the greater the reduction in surface residue. On the other hand, percent residue cover is most critical for erosion control from the seedbed establishment period until significant crop canopy is attained, especially on those fields where row-
crops are grown. Therefore, plant material either growing vegetation or crop residues on or near the soil surface appears to have the greatest promise for erosion control.

In general, soil erosion in the F. R. Germany is not considered to be a serious problem. On the other hand, we do find numerous regions where eroded and degraded soils are predominant on arable land. They are often cultivated in large field units and water or wind erosion removes the fertile part of the topsoil.

The Federal Government of Germany has recognized that soil resource base in Germany may require protection and has initiated conservation tillage programmes. One part of this system is the 'mulch-seed concept'.

CONCEPT AND THEORY

In Germany, conservation tillage is a fairly recent but increasingly used term that has somewhat different meaning than that used in the U.S. Mannering et Fenster (1983) have defined conservation tillage in the U.S. as "any tillage system that reduces loss of soil and/or water relative to conventional tillage. Often a form of noninversion tillage that retains protective amounts of residues on the soil surface." The Conservation Tillage Information Center (CTIC, 1984) has refined this definition to require a minimum of 30% surface residue cover after planting.

In Germany, conservation tillage refers to a level of tillage intensity intermediate between conventional tillage (high intensity) and zero tillage, Fig. 1.

<table>
<thead>
<tr>
<th></th>
<th>conventional tillage system</th>
<th>conservation tillage system</th>
<th>zero-tillage system</th>
</tr>
</thead>
<tbody>
<tr>
<td>stubble</td>
<td></td>
<td>†</td>
<td>-</td>
</tr>
<tr>
<td>tillage</td>
<td></td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>primary</td>
<td>†</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>tillage</td>
<td></td>
<td>loosening the soil if necessary</td>
<td>-</td>
</tr>
<tr>
<td>secondary</td>
<td>†</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>tillage</td>
<td></td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>planting</td>
<td>†</td>
<td>mulch seeding</td>
<td>†</td>
</tr>
</tbody>
</table>

Fig. 1: Tillage intensity for conservation tillage systems in relation to conventional and zero-tillage

In effect, conservation tillage as perceived in Germany is a modification of the two extreme tillage systems and emphasizes conservation goals (Sommer et al., 1981). Mulch seeding with
or without (- in Fig. 1) is a main part of the concept of conservation tillage systems.

The mulch-seed as a part of conservation tillage and integrated crop production is an efficient possibility to reduce or prevent soil erosion. Unquestionably, the most effective way to eliminate soil erosion by water or wind is to have living or dead vegetation on the soil surface after planting (mulch-seed without seedbed preparation). But sometimes the mixture of soil and crop residues (mulch-seed with seedbed preparation) is also a good possibility to reduce erosion, at least in the case of water erosion.

RESULTS

Since Bauemer et Pape (1972) have tested under German climatic conditions how a continuous zero-tillage system affects growth and yield of sugar-beet the development of effective conservation tillage systems including the advantages of winter cover crops has become a research field in the F. R. Germany.

Research on soil and crop responses to conventional and conservation tillage systems has been conducted since 1979 (Sommer et al., 1981).

A crop rotation of sugar-beets - winter wheat - winter barley - winter cover crop representative of local cropping systems were established. Sugar-beet tops or chopped straw from the winter small grain was incorporated with stubble tillage to control weed and/or volunteer plants. Permanent traffic lanes on 2.5 m beds were established on a loamy soil.

The soil physical results show some differences between the conventional plot (P) and the conservation tillage plot (Rh), Fig. 2.

Fig. 2: Penetrometer resistance of field capacity moisture content as a function of depth for two tillage treatments and wheel track comparison
No significant differences in sugar-beet yield or total sugar content were observed due to tillage system, Fig. 3.

![Soil: loamy sand. Treatments: conventional tillage (plough: P), conservation tillage (rotary harrow: S), conservation tillage (rotary tiller: F).](image)

Fig. 3: Sugar-beet yields and total sugar content for the conventional and conservation tillage systems of an experimental field study at Braunschweig.

Similar results have been obtained with demonstration field experiments on several farms since 1983 where mulch-seed operations were used for growing sugar beets (Fig. 4).

![Fig. 4: Sugar-beet yields and total sugar content for the conventional (100%) and conservation tillage systems on 15 farms in Lower Saxony.](image)

The German concept of conservation tillage allows for soil loosening by non-inversion tillage before establishing a winter cover crop following winter barley. Many farmers grow a winter cover crop to aid in soil fertility, erosion protection, and weed suppression. However, farmers using conventional tillage systems plow in the cover crops to obtain a soil surface condition suitable for conventional planters.
An adaptation to this conventional system would be to leave the cover crop through the winter months to be killed either by frost or herbicides in the spring. Planting directly into the cover crop residues results in continuous soil coverage from August through June at which time the following crop of sugar-beets or maize begins to provide adequate coverage.

Different types and varieties of winter cover crops are adapted to German conditions. The most popular ones are late summer-seeded phacelia, mustard, oil radish or rye. They are easy to establish and growing fast. Legumes as vetch or lupins supply some nitrogen that can be used by a spring-seeded crop as sugar beets or maize.

**SUMMARY AND OUTLOOK**

There is no doubt that the concept of conservation tillage with crop-specific and soil-specific types of systems has the potential for soil protection.

Research data and practical experiences support the fact that conservation tillage can prevent erosion, stabilize soil structure and reduce costs by

- reducing tillage intensity compared with conventional tillage and
- leaving crop residues on or near the soil surface.

However, there are obstacles to adoption of conservation tillage systems which require further clarification:

- lack of accurate, useful information
- lack of research data for site-specific soil types, crops etc.
- lack of weed, insect, and disease management programmes
- lack of conservation tillage implements and planting equipment.

**REFERENCES**


STUDY OF THE METHOD OF RATIONAL SOIL TILLAGE OF HEAVY SOILS ON WHEAT YIELD

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² Institute for Application of Science in Agriculture, Beograd (Yugoslavia)

ABSTRACT

Our researches, performed in the years 1985 and 1986, relate to the study of three soil tillage systems with different varieties of seedbed preparation.

In the first year, classic tillage (average wheat grain yield 5.47 t/ha) regardless to the varieties of seedbed preparation, resulted in lower yield than in the case of reduced (5.56 t/ha) and rational tillage (5.74 t/ha). The pre-sowing preparation of the soil performed with agricultural implements having active working parts with PTO drive, did not give bigger yields compared to the classic variety of pre-sowing preparation (in 1985), but the yield in the year 1986 on varieties where the pre-sowing preparation was made with rotating implements, were somewhat bigger but statistically unjustified.

In both studied years, there are no significant differences in yield among all tillage systems, but the difference in time utilization and fuel consumption is significant.

INTRODUCTION

For more than ten years researches were made and successfully applied in Yugoslavia, for different systems of soil tillage for wheat production without the use of plough. Most widely applied is reduced tillage after the preceding crops such as sugar beet, soybean etc., for which the soil is tilled with traditional plough deeper than 25 cm.

Since research results in general production have shown that the same or even somewhat higher yields were obtained through new tillage systems, the interest of science and practice has stimulated further studies and improvements of the reduced soil tillage systems.

The wider use of reduced soil tillage was influenced by dry seasons when ploughing of the soil is not possible or defective; the tilled part of the soil having big and hard lumps, pre-sowing preparation is difficult and complicated, sowing is not precise, and the consumption of time and fuel considerably higher.

METHOD

The experiments were carried out as per the method of striped blocks (Zadde), with eight varieties and four repetitions. Three systems of basic tillage were studied: (a) classic tillage by plough, (b) reduced tillage system by heavy duty disc harrow and (c) rational tillage system by chisel plough. Each system of basic tillage system was investigated: by classic procedure for pre-sowing preparation (disc harrow and pulvi mulcher) and with implements having active working parts with PTO drive.

The soil type is hydromorphic semi-terrestrial dark, with 74.3% clay in the layer up to 25 cm depth. The preceding crop was sugar beet. Fertilization was standard and of the same level for all varieties of tillage. Wheat variety was "Jugoslavija".
We have examined (a) the grain yield, (b) the soil resistance during tillage, (c) fuel consumption, (d) physical characteristics of the soil, and (e) development of crops.

RESULTS AND DISCUSSION

(a) Yield analysis

Table I. The influence of soil tillage system on wheat yield.

<table>
<thead>
<tr>
<th></th>
<th>Grain yield, t/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1985</td>
</tr>
<tr>
<td><strong>Classic Tillage</strong></td>
<td></td>
</tr>
<tr>
<td>- Ploughing plus classic seed bed preparation</td>
<td>5.59</td>
</tr>
<tr>
<td>- Ploughing plus combined heavy duty field cultivator(^1) plus combine(^2)</td>
<td>5.19(^{-1})</td>
</tr>
<tr>
<td>- Ploughing plus rotary digger plus combine</td>
<td>5.54</td>
</tr>
<tr>
<td>- Ploughing plus combine</td>
<td>5.67</td>
</tr>
<tr>
<td><strong>Average:</strong></td>
<td>5.47</td>
</tr>
<tr>
<td><strong>Reduced Tillage</strong></td>
<td></td>
</tr>
<tr>
<td>- Disc harrowing plus classic seed bed preparation</td>
<td>5.54</td>
</tr>
<tr>
<td>- Disc harrowing plus combine</td>
<td>5.59</td>
</tr>
<tr>
<td><strong>Average:</strong></td>
<td>5.56</td>
</tr>
<tr>
<td><strong>Rational tillage</strong></td>
<td></td>
</tr>
<tr>
<td>- By chisel plough plus classic seed bed preparation</td>
<td>5.94</td>
</tr>
<tr>
<td>- By chisel plough plus combine</td>
<td>5.55</td>
</tr>
<tr>
<td><strong>Average:</strong></td>
<td>5.74</td>
</tr>
</tbody>
</table>

| LSD 5% | 0.54  | 0.75  |
| 1%     | 0.74  | 1.03  |

\(^1\) The heavy duty field cultivator is combined of elastic springed cultivator, grated roller and cambridge roller
\(^2\) The combine consists of rotavator and seed drill.
\(^{-1},^{-2},^{-3}\) The crop was partially damaged by game.

In the year 1985, there was significant difference in yield for all varieties of tillage, while in the year 1986 higher yield was obtained in cases where for the seed bed preparation implements with active working parts and PTO drive were used. These statistically unjustifiable differences were the consequence of lower soil humidity so that the seed bed preparation with rotating implements was of higher quality and the sowing more precise.
(b) Examination of energy and other parameters

Table II. The influence of soil tillage system on specific resistance (daN/cm²)

<table>
<thead>
<tr>
<th>Tillage system</th>
<th>Year</th>
<th>Depth of work /a/</th>
<th>Specific soil resistance /k/</th>
<th>Fuel consumption /Q/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ploughing</td>
<td>1985</td>
<td>24.5</td>
<td>0.755</td>
<td>28.87</td>
</tr>
<tr>
<td></td>
<td>1986</td>
<td>25.0</td>
<td>1.450</td>
<td>60.20</td>
</tr>
<tr>
<td>By chisel plough</td>
<td>1985</td>
<td>23.0</td>
<td>0.543</td>
<td>18.51</td>
</tr>
<tr>
<td></td>
<td>1986</td>
<td>22.0</td>
<td>1.020</td>
<td>27.80</td>
</tr>
</tbody>
</table>

The soil resistance at tillage is in direct dependence with the soil water content and soil compactness. The water content at 10-25 cm, at the time of tillage in 1986 was 15.5% and in the year 1986, 9.2%.

(c) Fuel consumption

Table III. The influence of soil tillage system on fuel consumption

<table>
<thead>
<tr>
<th>Tillage variety</th>
<th>Fuel consumption l/ha (Tillage and sowing)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1985</td>
</tr>
<tr>
<td>Ploughing plus classic seed bed preparation</td>
<td>72.1</td>
</tr>
<tr>
<td>Ploughing plus heavy duty combined field</td>
<td>49.9</td>
</tr>
<tr>
<td>cultivate plus combine</td>
<td></td>
</tr>
<tr>
<td>Ploughing plus rotarydigger plus combine</td>
<td>56.2</td>
</tr>
<tr>
<td>Ploughing plus combine</td>
<td>57.4</td>
</tr>
<tr>
<td>Harrowing plus classic seed bed preparation</td>
<td>45.2</td>
</tr>
<tr>
<td>Harrowing plus combine</td>
<td>33.3</td>
</tr>
<tr>
<td>By chisel plough plus classic seed bed preparation</td>
<td>43.8</td>
</tr>
<tr>
<td>By chisel plough plus combine</td>
<td>39.1</td>
</tr>
</tbody>
</table>

The most significant difference in fuel consumption is between ploughing with classic seed bed preparation and reduced tillage in both researched years. The fuel consumption was bigger for the seed bed preparation in the year 1986, since the soil water content was lower upon ploughing, large and compact lumps remained for which more machine trips were required. Under such conditions, it is more rational for seed bed preparation to use implements with active working parts, in which case the fuel consumption is lower and the seed bed preparation of a better quality.
In our researches, we have determined small deviations in obtained yield, among different soil tillage systems. This was achieved also in previous researches in Yugoslavia (Konstantinović, 1987; Dakić, 1984).

For tillage and seed bed preparation of soil having heavy mechanical structure, especially if the same is compact and with low water content, ploughing can be replaced with more shallow harrowing, or with more deep chisel plough treatments, at reduced fuel consumption obtaining the same yield.

The application of implements with active working parts for seed bed preparation is still to be studied, since their rational application depends on the soil condition and water content at the time of tillage. The research of combined agricultural implements and their rational application adjusted to the climate features and soil characteristics, is also of significance.

In the year 1985 increased weed population was not observed so that there was no need for plant protection, while in the year 1986, the increase of wide leaf weed was noticed, so that plant protection was made for all varieties of tillage.

CONCLUSION

The classic soil tillage in our researches did not give bigger yield compared to reduced and rational tillage.

In the first year, there was no difference in obtained yields among different varieties of pre-sowing preparation. In the second year the differences were slightly bigger, but statistically unjustified.

The soil resistance at tillage was considerably higher when the humidity content is lower. Ploughing and seed bed preparation considerably increased the fuel consumption, compared to the reduced and rational tillage.

The reduced tillage with heavy duty disc harrow (7-12 cm depth) on soils with heavy mechanical structure, should be rationalized by using chisel ploughs (15-25 cm depth), since after harrowing untilled parts of soil can remain, interfering with the development of wheat root. By deeper tillage with chisel plough, the possible defects of disc harrow are eliminated enabling a better water infiltration.

The researches of new soil tillage systems are continued.

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THE EFFECTS OF TILLAGE AND FERTILIZATION ON THE YIELD AND WEED INFESTATION OF WINTER WHEAT, SPRING BARLEY AND MAIZE

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ABSTRACT

The effects of tillage and fertilization on the yield and weed infestation were studied in winter wheat, spring barley and maize.

The trial was a randomized split plot design in four replications. Beside these factors the yields were considerably affected by precipitation, too. In maize autumn ploughing gave the best results in respect of weed infestation and yield, as well. In winter wheat heavy-duty-cultivator provided the optimum at the highest NPK level. Use of the wide-spread discing caused unfavourable effects in all the three crops. Zero tillage cannot be recommended, despite of its temporary success in maize, due to the frequency of drought in Hungary.

INTRODUCTION

In Hungary winter wheat and maize are grown in 50% of the whole arable area /ca. 2,4-2,5 million ha/. During the last decade the average yield for wheat and maize varied from 5 to 7 and from 4 to 5,5 t/ha, respectively. Fluctuation of the yield can be attributed partly to changes in precipitation. Under the climatic conditions of Hungary the drought is frequent thus, tillage has an important role to play in crop production. In case of spring crops reception and conservation of precipitation are the most important, whereas autumn crops require adequate seed-bed even under dry conditions. In case of wheat conventional tillage /ploughing/ is more and more replaced by shallow cultivation depending upon tillage implements. Improvement of economy requires a critical survey of the general use of fertilizers so as to correlate the tillage systems with the nutrient supply. Beside these, weed control is to be considered as an important co-factor. /Erbach et al, 1986, Hay et al, 1978, Ketcheson, 1980, Videnovic et al, 1986/.

MATERIALS AND METHODS

In 1977 we started a long-term trial at the Univ. Gödöllő to study the effects of tillage and fertilization in winter wheat, spring barley and maize. The trial was a randomized split plot design with two factors using four replications, the plot size was 100 m². The soil was Raman’s brown forest soil, sandy loam...
with a humus content of 1.5%. The pH was 7.2. The P$_2$O$_5$ content was 120 ppm, the K$_2$O content was 180 ppm.

Tillage treatments /factor A/

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Crops</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A$_1$</td>
<td>zero-tillage</td>
<td>w. wheat, s. barley maize</td>
</tr>
<tr>
<td>A$_2$</td>
<td>strip-cultivation</td>
<td>discing /15cm/</td>
</tr>
<tr>
<td>A$_3$</td>
<td>autumn ploughing</td>
<td>loosening /60cm/ +</td>
</tr>
<tr>
<td>A$_4$</td>
<td>rototilling</td>
<td>discing /15cm/</td>
</tr>
<tr>
<td>A$_5$</td>
<td>spring ploughing</td>
<td>heavy-duty-cultivator /20cm/</td>
</tr>
<tr>
<td>A$_6$</td>
<td>autumn ploughing</td>
<td>loosening /60cm/ +</td>
</tr>
</tbody>
</table>

Fertilization treatments /factor B/ /kg/ha/

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Crops</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>B$_1$</td>
<td>w. wheat, s. barley maize</td>
<td>N 0, /0/</td>
</tr>
<tr>
<td>B$_2$</td>
<td>45, /65/</td>
<td>P$_2$O$_5$ 64, /50/</td>
</tr>
<tr>
<td>B$_3$</td>
<td>90, /130/</td>
<td>K$_2$O 167, /130/</td>
</tr>
<tr>
<td>B$_4$</td>
<td>135, /195/</td>
<td></td>
</tr>
</tbody>
</table>

The crop sequence was as follows: maize /for 5 years/ spring barley maize maize winter wheat winter wheat

During the trial weed control and other plant protection activities were carried out according to the Hungarian standard. In maize mechanical weed control was also applied. The annual precipitation varied between 420 and 630 mm. The 50 years' average is 560 mm.

RESULTS AND DISCUSSION

The summarized results reveal no significant differences between spring cultivation and zero tillage in respect of yield at the highest NPK level, except autumn ploughing. However, in practice ploughing cannot be carried out in adequate quality and time. In such cases, beside autumn ploughing /treatment A$_6$/ the average yield up to the 3rd NPK level was only suppressed by rototilling /treatment A$_3$/.
the usual implement, resulted in the lowest yield in all the four fertilizer treatments.

Table 1. The effects of fertilization and tillage on the yield of maize /t/ha/

<table>
<thead>
<tr>
<th>Tillage /A/ /depth/</th>
<th>Fertilization /B/</th>
<th>B₁</th>
<th>B₂</th>
<th>B₃</th>
<th>B₄</th>
</tr>
</thead>
<tbody>
<tr>
<td>A₁ zero-tillage</td>
<td>B₁₁</td>
<td>5,269</td>
<td>6,272</td>
<td>6,957</td>
<td>7,228</td>
</tr>
<tr>
<td>A₂ strip-cultivation /15 cm/</td>
<td>B₁₂</td>
<td>5,450</td>
<td>6,388</td>
<td>6,904</td>
<td>7,269</td>
</tr>
<tr>
<td>A₃ rototilling /15 cm/</td>
<td>B₁₃</td>
<td>5,551</td>
<td>6,576</td>
<td>7,022</td>
<td>7,219</td>
</tr>
<tr>
<td>A₄ discing /15 cm/</td>
<td>B₁₄</td>
<td>5,211</td>
<td>5,994</td>
<td>6,524</td>
<td>7,054</td>
</tr>
<tr>
<td>A₅ spring ploughing /25 cm/</td>
<td>B₁₅</td>
<td>5,412</td>
<td>6,201</td>
<td>6,641</td>
<td>7,382</td>
</tr>
<tr>
<td>A₆ autumn ploughing /25 cm/</td>
<td>B₁₆</td>
<td>6,323</td>
<td>7,156</td>
<td>7,803</td>
<td>8,603</td>
</tr>
</tbody>
</table>

/A/ Tillage LSD /P = 0.05/ = 0.488 /t/ha/
/B/ Fertilization LSD /P = 0.05/ = 0.556 /t/ha/

Table 2. The effects of fertilization and tillage on the yield of winter wheat

<table>
<thead>
<tr>
<th>Tillage /A/ /depth/</th>
<th>Fertilization /B/</th>
<th>B₁</th>
<th>B₂</th>
<th>B₃</th>
<th>B₄</th>
</tr>
</thead>
<tbody>
<tr>
<td>A₁ zero-tillage</td>
<td>B₂₁</td>
<td>1,825</td>
<td>2,925</td>
<td>3,513</td>
<td>3,375</td>
</tr>
<tr>
<td>A₂ discing /15 cm/</td>
<td>B₂₂</td>
<td>2,900</td>
<td>4,775</td>
<td>5,825</td>
<td>6,325</td>
</tr>
<tr>
<td>A₃ loosening+discing /60 cm/ /15 cm/</td>
<td>B₂₃</td>
<td>3,425</td>
<td>5,325</td>
<td>6,438</td>
<td>7,025</td>
</tr>
<tr>
<td>A₄ autumn ploughing /25 cm/</td>
<td>B₂₄</td>
<td>4,150</td>
<td>5,375</td>
<td>6,650</td>
<td>6,500</td>
</tr>
<tr>
<td>A₅ heavy-duty-cultivator /20 cm/</td>
<td>B₂₅</td>
<td>3,788</td>
<td>5,575</td>
<td>7,050</td>
<td>7,138</td>
</tr>
<tr>
<td>A₆ loosening+ploughing /60 cm/ /25 cm/</td>
<td>B₂₆</td>
<td>4,375</td>
<td>5,500</td>
<td>6,050</td>
<td>6,200</td>
</tr>
</tbody>
</table>

/A/ Tillage LSD /P = 0.05/ = 0.965 /t/ha/
/B/ Fertilization LSD /P = 0.05/ = 0.943 /t/ha/

The results show that with average or less precipitation zero tillage causes a considerable yield-loss in Hungary even at the highest amount of NPK applied. Use of a heavy-duty cultivator /treatment A₅/ was excellent under dry conditions. The optimal quality of seed-bed could be obtained via this treatment, too. Except for zero tillage /treatment A₁/, no significant differences occurred in bulk density. Deep tillage /treatment A₄/ did not differ significantly from heavy-duty cultivator /treatment A₅/ at the highest NPK level, but it was uneconomical and unnecessary.
ESTIMATE OF WEED COVER

Table 3. The effects of tillage and fertilization on the weed cover in maize, %

<table>
<thead>
<tr>
<th>Tillage /A/</th>
<th>B(_1)</th>
<th>Fertilization</th>
<th>B(_2)</th>
<th>B(_3)</th>
<th>B(_4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A(_1)</td>
<td>12,96</td>
<td>6,35</td>
<td>8,54</td>
<td>4,34</td>
<td></td>
</tr>
<tr>
<td>A(_2)</td>
<td>8,23</td>
<td>6,05</td>
<td>7,63</td>
<td>2,34</td>
<td></td>
</tr>
<tr>
<td>A(_3)</td>
<td>26,28</td>
<td>22,15</td>
<td>3,56</td>
<td>6,78</td>
<td></td>
</tr>
<tr>
<td>A(_4)</td>
<td>9,25</td>
<td>8,17</td>
<td>1,96</td>
<td>1,66</td>
<td></td>
</tr>
<tr>
<td>A(_5)</td>
<td>1,97</td>
<td>2,96</td>
<td>10,31</td>
<td>1,00</td>
<td></td>
</tr>
<tr>
<td>A(_6)</td>
<td>0,26</td>
<td>1,06</td>
<td>3,25</td>
<td>0,36</td>
<td></td>
</tr>
</tbody>
</table>

/A/ Tillage LSD /P=0,05/ = 8,76 %/
/B/ Fertilization LSD /P=0,05/ = 7,16 %/
AXB LSD /P=0,05/ = 12,43 %/

The weeds were mainly composed of late-germinating annuals and perennials. Tillage and fertilization affected significantly the percentile weed cover, but without any significant interaction /p = 0,05/. We can state that the abundance of weeds was increased mostly when using a rotovator. The betweenplot differences were insignificant with or without tillage when taking the average of the four fertilizer levels. In general the percentile weed cover decreased in a dose-related fashion.

Table 4. The effects of tillage and fertilization on the weed cover in spring barley, %

<table>
<thead>
<tr>
<th>Tillage /A/</th>
<th>B(_1)</th>
<th>Fertilization</th>
<th>B(_2)</th>
<th>B(_3)</th>
<th>B(_4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A(_1)</td>
<td>15,53</td>
<td>13,84</td>
<td>11,76</td>
<td>13,25</td>
<td></td>
</tr>
<tr>
<td>A(_2)</td>
<td>3,30</td>
<td>2,23</td>
<td>1,03</td>
<td>1,24</td>
<td></td>
</tr>
<tr>
<td>A(_3)</td>
<td>2,61</td>
<td>0,98</td>
<td>2,51</td>
<td>9,21</td>
<td></td>
</tr>
<tr>
<td>A(_4)</td>
<td>4,91</td>
<td>7,33</td>
<td>6,12</td>
<td>9,81</td>
<td></td>
</tr>
<tr>
<td>A(_5)</td>
<td>0,23</td>
<td>1,02</td>
<td>0,90</td>
<td>1,03</td>
<td></td>
</tr>
<tr>
<td>A(_6)</td>
<td>0,12</td>
<td>0,02</td>
<td>0,20</td>
<td>0,81</td>
<td></td>
</tr>
</tbody>
</table>

/A/ Tillage LSD /P=0,05/ = 3,95 %/
/B/ Fertilizer LSD /P=0,05/ = NS
AXB LSD /P=0,05/ = 5,61 %/

In this case only tillage had a significant effect on the weed cover /p = 0,05/. Since then the weed cover of the zero tillage plots was significantly higher, compared to others'. We have to underline the unfavourable effects from the use of disc.

The effect of increasing the fertilizer dose is unambiguous: up to the 3rd dose level the weed cover was decreasing then it showed a considerable increase.
Table 5. The effects of tillage and fertilization on the weed cover in winter wheat, %

<table>
<thead>
<tr>
<th>Tillage /A/</th>
<th>Fertilization /B/</th>
<th>April /June/</th>
<th>April /June/</th>
<th>April /June/</th>
<th>April /June/</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>32.91</td>
<td>45.92</td>
<td>41.40</td>
<td>41.13</td>
<td>64.06</td>
</tr>
<tr>
<td>A2</td>
<td>4.84</td>
<td>3.40</td>
<td>0.96</td>
<td>3.66</td>
<td>0.67</td>
</tr>
<tr>
<td>A3</td>
<td>10.50</td>
<td>3.83</td>
<td>1.27</td>
<td>4.18</td>
<td>2.30</td>
</tr>
<tr>
<td>A4</td>
<td>1.76</td>
<td>3.59</td>
<td>0.36</td>
<td>3.64</td>
<td>0.17</td>
</tr>
<tr>
<td>A5</td>
<td>10.30</td>
<td>3.27</td>
<td>1.76</td>
<td>4.17</td>
<td>0.52</td>
</tr>
<tr>
<td>A6</td>
<td>0.16</td>
<td>0.20</td>
<td>0.23</td>
<td>0.33</td>
<td>0.17</td>
</tr>
</tbody>
</table>

Here we couldn’t estimate the characteristic weed cover on a single visit occasion due to the long vegetation season. So we conducted two estimates: in late-April then before harvest in mid-June.

In spring we found a significant interaction between tillage and fertilization treatments, that couldn’t be demonstrated later on.

In spring the increase of the fertilizer doses on zero tillage plots produced an increase in the weed cover. On the other plots the opposite happened, except ploughing and heavy-duty-cultivator treatments. The differences among the various tillage treatments are consistent, but non-significant /p=0.05/. Before harvest weeds weren’t significantly affected by fertilization, but reduction of the cover was evident at the highest dose. Again, no significant differences were noted among the various tillage treatments, except zero tillage.

According to weed estimates conducted on two occasions in spring the favourable weed infestation of the ploughed plots was later followed by a progressive spread of weeds. This phenomenon did not occur in case of loosening + ploughing /treatment A6/. The degree of pre-harvest weed infestation was the highest when using disc.

CONCLUSIONS

The yields of winter wheat and maize are considerably affected by tillage under the ecological and cropping conditions of Hungary. The yield-loss resulting from unfavourable tillage can be compensated by increasing doses of the fertilizers up to a certain extent only. In case of spring crops conservation of precipitation via the autumn tillage is the
most important. While in case of autumn crops the highest yield can be expected only by those treatments which ensure the adequate seed-bed even under dry conditions. Deep tillage could not result in a yield increase of winter wheat.

Concerning weed infestation of maize, autumn ploughing was the most favourable. Spring ploughing was less effective: the degree of weed cover could approximate to that of discing due to the vitality of the deep-rooting perennials. No difference was between strip and zero tillage in this respect. Weed infestation was mainly promoted by rototilling in case of annuals and perennials, as well.

In cereal crops zero tillage produced a progressive weed infestation. Ploughing and loosening + ploughing reduced significantly the weed flora at the early stage of growth. In case of ploughing this effect took an adverse tendency later on and proved less favourable, compared to heavy-duty-cultivator and loosening + ploughing. Fertilizers at increased doses reduced weed infestation to a greater extent in cereal crops, than in maize.

REFERENCES


INFLUENCE OF SOIL CULTIVATION METHODS ON SOIL STRUCTURE, BIOLOGY ACTIVITY AND YIELD

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Faculty of Agricultural Engineering Institute, Justus-Liebig-University, Giessen (FRG)

ABSTRACT

When the contact intensity of soil cultivation tools is reduced, power and energy requirements can be cut considerably and, as a result, damage to the soil caused by pressure and slip minimised to a large extent. Homogeneous mixing-in of organic remains leads to major improvements with regard to sludging and erosion protection at locations which are at risk. Conversion of these substances is accelerated, the biological activity is increased and, as a result of these interrelations, the natural fertility of the soil and the crumb and structural stability is improved.

INTRODUCTION

For some time now, farmers have had to face accusations of being responsible for destroying the "natural fertility of the soil" because in view of the awareness of the general public on questions of environmental impact, the methods employed in the farming sector - the intensity of soil cultivation - are the subject of a considerable amount of criticism. Visible signs of this gradual loss of the "natural fertility of the soil" are soil erosion by water and wind, sludging and caking of the surface of the fields, as well as compaction to considerable depths which acts as a hindrance to water infiltration and root growth.

In spite of this, however, these negative effects could be avoided if reduced soil cultivation methods were firstly to be accepted by the people working "in the field" and, secondly, actually put into practice to a greater extent. The prime prerequisite for determining the influence of soil cultivation methods on the soil substrate, also from the point of view of soil protection, is the choice of suitable equipment from the extensive range available on the market today. If we classify soil cultivation equipment according to the tool form and the function it fulfils, there appear to be only very few soil cultivation methods (Fig. 1) which clearly differ from one another according to their contact intensity, contact depth and the range of applications they offer (Tebrügge 1986).

METHODS AND RESULTS

Unfortunately, suitable methods are still not available to allow farmers to assess the condition of the soil structure quickly and reliably. In addition to the aggregation success,
Decreasing contact intensity

<table>
<thead>
<tr>
<th>Function</th>
<th>Plough + secondary tillage (P)</th>
<th>Heavy cultivator with rotary harrow (HR)</th>
<th>Winged share cultivator with rotary harrow (WR)</th>
<th>Rotary cultivator seeding (R)</th>
<th>Direct drilling (D)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F d</td>
<td>35</td>
<td>15</td>
<td>30</td>
<td>15</td>
</tr>
<tr>
<td>Turning</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loosening</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cled breaking</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mixing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>working in</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tamping down</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 1: Assessment criteria of soil cultivation implements

![Graph showing power requirements](image)

Fig. 2: Power requirement of primary and secondary tools and aggregation after secondary cultivation - slate 16.5% H₂O

which is generally shown as the weighted mean diameter (WMD) of the soil aggregates, the energy requirement can also be used to assess the contact intensity in the soil. Using sil soil as an example, Fig. 2 illustrates the demand of the primary tools as the tractive power requirement and of the secondary tools as the rotatory power requirement per metre of working width. In spite of the considerably higher energy requirement for the
plough version with subsequent rotary secondars cultivation, the aggregate mixture with a weighted mean diameter of 15.8 mm after cultivation appears to have a higher value as compared with the cultivator versions with approx. only 10 mm each.

The reasons for this lie in the turning action of the plough due to which more or less coarse-clod soil is transported from the cultivation depth zone to the surface, depending on the soil type.

The penetration resistance (N/cm²) of the soil can also be regarded as a further factor decisive for improving the structural conditions. The almost straight resistance value curve for the direct drilling method (D), which is lower than the plough method in the 15 cm zone and the cultivator method in the 22 cm zone, is particularly worthy of note. The overall resistance value curve for the D method indicates that a uniformly stable soil structure has developed over the years. The relatively low resistance values for the P method in September increase up to November at a rate which is considerably higher than the soil resistance values for the cultivator and direct drilling methods. The logical conclusion which can be drawn from this is that ploughing works leads to overloosening and that this is inherently very unstable.

Moreover, investigations conducted by Vorderbrügge (1985) with regard to the function fulfilled by coarse pores (larger than 50 microns: P 18 %, D 13 %) have revealed that, in the case of the D method, identical air permeability values result despite the considerably smaller share of large pores than in the case of the P method. This indicates that a high level of coarse-pore continuity results when the soil is allowed to rest over the course of time.

Numerous investigations indicate that the living conditions of the organisms involved in converting the organic material are improved considerably by working in plant remains in the upper topsoil level as homogeneously as possible, the consequence of this being that the conversion and decomposition process for the plant remains and, thus, so-called biostabilisation is enhanced as a result of the metabolic products (Beck, 1984). A decisive parameter for micro-organism activity is biological breathing measurement (CO₂/50g soil). Here, the non-turning soil cultivation methods indicate considerably 40 % higher biological breathing activity, in particular in the topsoil zone and over the course of time (Fig. 3).

Soil organisms improve the soil structure, digging species such as earthworms, for example, constantly producing stable cavity systems which are beneficial for infiltration and ventilation. The results in the 5th year of trials clearly indicate this interrelation (Fig. 4). However, the comparatively high nutrition requirement of the D method also explains why there is no accumulation of harvest remains on the direct drilling plots, even when a straw covering is applied every year.
Fig. 3: Biology breathing (mg CO₂/50 g soil) under the influence of different soil cultivation methods—6th trial year.

Fig. 4: Number of organisms, biological mass, nutrition requirement, tube volume and earthworm release for different types of soil cultivation (cereal crop rotation, annual straw fertilizing. 5th year of trials, location: Wernborn/Ts.)
Fig. 5: Infiltration as influenced by various types of cultivation - mm $H_2O-S$ (sandy loess - $13\% H_2O$) - 6th trial

Fig. 6: The tendency of different cultivation
An increasing phenomenon, is soil erosion, in particular that of silty soil types. The extent to which soil cultivation methods can play a role in providing soil protection by preventing surface sealing in the form of sludging (a major cause of soil erosion) can be illustrated using measurement of the water intake capacity (Fig. 5). This indicates that methods which mix in the harvest remains close to the surface have a more positive effect with reference to the water balance (absorption capacity to that of a sponge), erosion and sludging protection as compared with the ploughing method.

In addition to the effects of reduced soil cultivation on soil physics and soil biological parameters outlined above, the long-term plant yields are the focal point of interest on the part of farmers. Contrary to the cereal crop yields (no major differences), sugar-beet growth in trial year 1983 and 1986 showed a greater dependency on the soil type and soil cultivation method. While on sandy soil using the direct drilling method, i.e. six years of absolute O-type cultivation, small, split beets were harvested, perfect beets developed in the loess and heavy warp clay soil, in particular where the D method was employed. In heavy soil, on the other hand, the high sensitivity to compaction shown by the soil loosened by the plough led to distinctly lower yields as compared with the conventional method. The reducing methods HR und WR produced high to very high yields. The second rotation (1986), for which it can be assumed that a specific structural condition of the soil has developed after 6 years of different contact intensity, also produced similar results with high yield certainty in favour of the reduced methods.

SUMMARY

When reduced contact intensity is employed consistently and seed placement techniques in keeping with the system are observed, the upward and downward trends illustrated in Fig. 6 can be expected.

Rational, gentle soil cultivation serves a back-up function in order to preserve or develop a permanent optimum soil condition. The saying "Less is often more" can also apply in a figurative sense to soil cultivation and must be exploited to the full in the sense of economically attainable benefits.

REFERENCES


EFFECTS OF GRASS AND LEGUMES AS A GREEN MANURE CROP ON GROWTH, YIELD AND NITROGEN RESPONSE OF SUGAR BEET

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ABSTRACT

The need for green manures has increased to maintain organic matter content and soil workability, because of the high frequency of root crops in the crop rotation of intensively managed Dutch cropping systems. Compared to grass green manuring, less information is available on the quantitative effects of white and red clover as green manures on the yield and nitrogen response of the successive crop (mainly potato or sugar beet). To establish the optimum rate of fertilizer nitrogen, it is important to study the influence of the various green manure crops on the nitrogen response of arable crops. A field experiment is described in which the effects of incorporating grass or clover as a green manure on yield and nitrogen economy of sugar beet are analyzed.

INTRODUCTION

Over the last 30 years the total area of arable land in the Netherlands has decreased by 200 000 ha to 780 000 ha in 1987. On the sandy soils in the eastern and southern part of the country rye has been largely replaced by a monoculture of forage maize, which in 1987 occupied 197 000 ha. Intensification and specialization have resulted in a rather narrow crop rotation. On the heavier soils the major crops are potatoes, sugar beet and cereals, mainly winter wheat and spring barley; on the sandy soils forage maize is the predominant arable crop. Occasionally minor crops like faba beans, green peas, grass for seed production, onions, bulbs and vegetable crops are included in the rotation.

In crop rotations comprising 50% root crops cultivation of green manure crops becomes increasingly important to maintain the organic matter content of the soil. Soils with an effective organic matter content of 0.02-0.04 g g⁻¹ require an annual supply of 1200-1500 kg ha⁻¹ organic material to maintain its organic matter content (Preuter, 1986). Direct effects of green manures relate to soil protection and soil improvement, such as higher resistance to wind and water erosion, buffering of mobile nutrient elements, nitrogen fixation by leguminous species and improved trafficability. The indirect effects, such as activation of the soil flora and fauna, earlier workability in spring and increased soil fertility are much more difficult to quantify, but have a positive influence especially under extreme weather conditions. Soil fertility, is often an elusive term, that can at least partly be made explicit by quantification of the flows of specific nutrient elements such as nitrogen in the soil-plant system. In a rotation including green manure, fertilizer nitrogen can either be applied directly to the main crop, or it can be given partly or in full to the green manure crop in the preceding autumn. In the case of clovers, nitrogen supply originates from atmospheric nitrogen through symbiotic fixation.
In the experiments reported here, emphasis was on the effects of grasses and clovers as green manure crops on growth, nitrogen use and yield of the subsequent crop of sugar beet.

**MATERIAL AND METHODS**

The experiments were carried out on a heavy loam. The rotation in the experiments was winter wheat (+ green manure), sugar beet, winter wheat (+ green manure), potatoes, winter wheat (+ green manure). The green manure crops, sown in April under the cover crop winter wheat, were grass, white clover and red clover. After harvesting the winter wheat, 0, 100 and 200 kg ha\(^{-1}\) of nitrogen was applied to the grass. In November, the green manure crops were plowed in, after determination of above-ground biomass and nitrogen content. In spring, five nitrogen fertilizer treatments were superimposed on each of the green manure treatments as a basic dressing. The experimental lay-out was a split-plot design with four replicates. In spring mineral-nitrogen dynamics in the soil was followed, and at harvest dry matter production, sugar yield and nitrogen content of the main crop were determined.

**RESULTS AND DISCUSSION**

The degree of success of the green manure crop is partly determined by the competitive power of the cover crop winter wheat, which can be influenced by nitrogen fertilizer application, as that affects canopy development and hence competition for light. That may be translated in yield differences as shown in Table I for different fertilizer application strategies. A single dressing in spring almost always results in lower yields than a split application. In general, a modest application in early spring followed by a topdressing at ear emergence, results in the highest grain yields. However, the main interest here is in the performance of the green manure crops, hence a visual estimate of the degree of success of a the white clover crop is also given in Table I which shows that despite the competitive effects, high wheat yields do not necessarily prevent success of the green manure crop.

Table I. Wheat yields (kg/100 m\(^2\), 17% moisture) and visual estimate of the quality of the stands of undersown white clover (in brackets; 10: good; 5: medium) in relation to method of nitrogen application.

<table>
<thead>
<tr>
<th>Total N dressing (kg/ha)</th>
<th>105</th>
<th>140</th>
<th>175</th>
</tr>
</thead>
<tbody>
<tr>
<td>N-split</td>
<td>105</td>
<td>70+35</td>
<td>35+70</td>
</tr>
<tr>
<td>Bouwing 1978</td>
<td>73(7)</td>
<td>73(6)</td>
<td>76(7)</td>
</tr>
<tr>
<td>Bouwing 1979</td>
<td>72(7)</td>
<td>76(8)</td>
<td>75(9)</td>
</tr>
<tr>
<td>Eest 1978</td>
<td>95(6)</td>
<td>98(6)</td>
<td>100(8)</td>
</tr>
<tr>
<td>Eest 1979</td>
<td>79(6)</td>
<td>81(8)</td>
<td>78(9)</td>
</tr>
</tbody>
</table>

The effect of the green manure crops on the subsequent main crop is a function of the total amount of biomass produced and its nitrogen content. In the experiments, only above-ground biomass is taken into account, hence the contribution of stubble and roots is discarded,
Biomass production and nitrogen yield of the various green manure crops ranged from 2.2 to 5.0 t ha⁻¹ of dry weight and 30 to 136 kg ha⁻¹, respectively depending on crop species (Table II). Nitrogen uptake of the grass without nitrogen fertilizer represents net mineralization from organic material during its growth period, most of which is taken up after harvest of the wheat. The apparent recovery of the fertilizer was 66% for the 100 kg ha⁻¹ application rate and 53% for the 200 kg ha⁻¹ application rate. The actual recoveries are higher and probably more similar for the two application rates as nitrogen in roots and stubble has not been taken into account. The fate of the remainder of the fertilizer nitrogen is unknown, as mineral nitrogen in the soil profile was not determined in autumn.

Table II. Dry matter and nitrogen yield (kg/ha) of different green manure crops (1981-10-29).

<table>
<thead>
<tr>
<th>Crop Type</th>
<th>Dry Matter</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grass + 0 N</td>
<td>2200</td>
<td>30</td>
</tr>
<tr>
<td>Grass + 100 N</td>
<td>3800</td>
<td>96</td>
</tr>
<tr>
<td>Grass + 200 N</td>
<td>5000</td>
<td>136</td>
</tr>
<tr>
<td>White clover</td>
<td>3500</td>
<td>99</td>
</tr>
<tr>
<td>Red clover</td>
<td>4700</td>
<td>112</td>
</tr>
</tbody>
</table>

In this respect, however, the mineral nitrogen contents in the profile in spring are interesting (Table III). In early March the total amount of mineral nitrogen in the control treatment, i.e. without green manure, in the 0-1 m layer is 67 kg ha⁻¹ versus 49, 79 and 178 kg ha⁻¹, respectively after incorporation of the grass fertilized with 0, 100 and 200 kg ha⁻¹ in autumn. Quantitatively, these results are difficult to explain. If between incorporation of the green manure crops and the beginning of March microbial transformations and transport over the 1 m soil depth boundary would have been negligible, one would expect the mineral nitrogen content under the incorporated grass with 0 N to be about 35 kg ha⁻¹ lower than in the control, i.e. that amount being tied up in the organic material, allowing for 5 kg ha⁻¹ in stubble and roots. Assuming the effective N recovery of the applied fertilizer to be 70%, mineral N under the incorporated grass with 100 kg N ha⁻¹ would have to be about 30 kg ha⁻¹ higher, and under the incorporated grass with 200 kg N ha⁻¹ about 60 kg ha⁻¹ higher than under the incorporated grass with 0 kg N ha⁻¹. However mineral N under the non-fertilized grass is only 18 kg ha⁻¹ lower than under the control, hence some of the nitrogen must have mineralized from the organic material. The difference between the 0 N treatment and the 100 N treatment is 30 kg ha⁻¹, which would represent exactly the residual fertilizer N. It is, however, difficult to explain why no nitrogen would have been mineralized from this organic material having at incorporation a nitrogen content of 2.5% against 1.4% for the grass that did not receive nitrogen fertilizer. In the treatment where grass fertilized with 200 kg ha⁻¹ was incorporated, the mineral N store is about 125 kg ha⁻¹ higher than under the control, suggesting that a substantial amount of nitrogen was mineralized from the organic material, although the nitrogen content was only slightly higher than of the material that received 100 kg ha⁻¹.

The results for the red and white clover treatments are comparable to those for the grass fertilized with 100 kg ha⁻¹ i.e. the amounts of mineral nitrogen in the soil are practically the same, following incorporation of similar amounts of organic nitrogen. Overall, these data
Table III. Inorganic nitrogen (kg/ha) in two soil layers on the dates indicated.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>1-3-1982 0-60 cm</th>
<th>3-6-1982 60-100 cm</th>
<th>18-10-1982 0-60 cm</th>
<th>18-10-1982 60-100 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>38</td>
<td>29</td>
<td>82</td>
<td>29</td>
</tr>
<tr>
<td>Grass + 0 N</td>
<td>31</td>
<td>18</td>
<td>93</td>
<td>45</td>
</tr>
<tr>
<td>Grass + 100 N</td>
<td>55</td>
<td>23</td>
<td>119</td>
<td>59</td>
</tr>
<tr>
<td>Grass + 200 N</td>
<td>125</td>
<td>53</td>
<td>129</td>
<td>96</td>
</tr>
<tr>
<td>White clover</td>
<td>60</td>
<td>23</td>
<td>147</td>
<td>51</td>
</tr>
<tr>
<td>Red clover</td>
<td>70</td>
<td>25</td>
<td>140</td>
<td>53</td>
</tr>
</tbody>
</table>

could suggest that the presence of relatively large amounts of mineral N (grass + 200 kg ha⁻¹) has a stimulating effect on organic matter decomposition (priming effect). Then only the result for the treatment grass + 100 N is inexplicable.

Between early March and early June net mineralization continues in all treatments. In the control treatment 45 kg ha⁻² is added to the mineral N store during this period. If again losses due to leaching and denitrification are assumed to be negligible, that amounts to a net mineralization rate of about 0.5 kg ha⁻¹ d⁻¹, a rather low value (Greenwood et al., 1985). In all other treatments, except grass + 200 N, the average rate of net mineralization is about 1 kg ha⁻¹ d⁻¹. The fresh organic material incorporated thus also provides about 0.5 kg ha⁻¹ d⁻¹. It could be argued that in the grass + 200 N treatment the easily decomposable material had already been decomposed before the beginning of March, so that only relatively resistant material is still present.

Considering the final situation in early June, it appears that after the grass crop, without any nitrogen amendment the total amount of mineral N is 27 kg ha⁻¹ higher than in the control. This could be due to lower losses in winter because the nitrogen was 'stored' in organic form. The fertilizer nitrogen added to the grass in autumn is 'recovered' in mineral form only to a very limited extent: the total mineral nitrogen store after incorporation of grass fertilized with 100 kg ha⁻¹ is 40 kg ha⁻¹ higher, that after incorporation of the grass fertilized with 200 kg ha⁻¹, 87 kg ha⁻¹ higher than after incorporation of the non-fertilized grass. Hence, only about 40% of the nitrogen fertilizer applied is present in mineral form at the beginning of the growing season of the sugar beet, i.e. a substantial part of that nitrogen must still be in organic form.

The situation at the end of the growing season is illustrated in Figure 1, consisting of three quadrants (de Wit, 1953). In quadrant I the relation is given between nitrogen uptake and total dry matter yield of the sugar beet crop, in quadrant IV that between nitrogen fertilizer application to the sugar beet and total nitrogen uptake. In quadrant II which can be constructed by combining the other two, the relation is given between nitrogen fertilizer application and total dry matter yield. A presentation as that in Figure 1 facilitates analysis of fertilizer experiments, as it allows separation of the effect of fertilizer application on uptake and that of increased uptake on dry matter production.
The lines in quadrant IV are essentially parallel for all treatments and vary only in the intercept with the uptake axis. Thus the uptake without fertilizer application to the sugar beet ('base uptake') differs, but the increase in uptake per unit increase in application rate, i.e. the recovery fraction, is practically constant. The base uptake in the control treatment is about 140 kg ha⁻¹, i.e. about 30 kg ha⁻¹ more than the mineral N store at the beginning of June. After harvest the amount of mineral N in the profile is only 19 kg ha⁻¹ (Table III). The average net mineralization rate over the growing season amounts thus to about 0.37 kg ha⁻¹ d⁻¹. Base uptake in the treatments where grass was incorporated was 148, 185 and 210 kg ha⁻¹ for the situation with 0, 100 and 200 kg ha⁻¹ applied in autumn, respectively. When these values are compared to the mineral N stores in June and October, average net mineralization rates amount to 0.22, 0.23 and 0.05 kg ha⁻¹, respectively, hence in all cases lower than in the control. That could indicate that during decomposition of the components of the fresh organic material during that period, nitrogen is immobilized.

When comparing the base uptake values of the various treatments to the total input of mineral nitrogen, it appears that the fertilizer applied to the grass in autumn contributes only to a limited extent to the nitrogen uptake of the sugar beet (45 kg additional out of 100 kg, 70 kg out of 200).

The recovery fraction of the fertilizer nitrogen applied to the sugar beet is about 0.65, and does not vary among treatments. This efficiency of fertilizer use is relatively low, but considering the method of application not surprisingly low.
The situation is much more favourable for the leguminous green manures. Without any mineral nitrogen amendment the base uptake is 100 and 115 kg N ha$^{-1}$ higher than the control for the white and red clover, respectively. It is surprising that during decomposition of this material between early June and October net mineralization occurs (17 and 34 kg N ha$^{-1}$ more mineral N than in the control treatment), whereas its composition at the time of incorporation was very similar to the grass that received mineral nitrogen in autumn, at least in terms of nitrogen concentration.

Both total dry matter production and sugar yield (Figure 1) are proportional to nitrogen uptake at low levels of nitrogen availability, in agreement with other observations (van Keulen and van Heemst, 1982). At higher availabilities the relation gradually levels off, reflecting higher nitrogen concentrations in the harvested material. The variability at (very) high levels of nitrogen availability is higher for sugar yield than for dry matter production, presumably because sugar yield not only depends on total sugar production, but also on the efficiency of extraction which is affected by the concentration of noxious nitrogenous compounds in the beets (van Keulen and van Heemst, 1982).

CONCLUSIONS

In the trial described in this paper, which is part of a long-term experiment on the effects of green manures in crop rotations, it was shown that undersowing of grass results in higher availability of mineral N residues to the subsequent crop. Application of N fertilizer in autumn to stimulate grass production, results in incorporation of larger amounts of biomass in autumn, but that system is inefficient in terms of nitrogen availability to the subsequent main crop as only 35-45% of the fertilizer is recovered, compared to 65% of the fertilizer applied directly to that crop.

Incorporation of leguminous species in the rotation has a very favourable effect, leading to about 100 kg ha$^{-1}$ additional nitrogen availability to the subsequent crop. From other trials in this experiment it must be concluded, however, that yield stability of these legumes is rather low, i.e. if conditions are unfavourable, crop failure is not uncommon.

Analysis of the results of this trial emphasize again that the processes affecting the nitrogen balance in the soil are poorly understood, and that it is therefore difficult to predict the consequences of different management practices on nitrogen and organic matter dynamics. More explanatory research in this area is thus necessary.

REFERENCES


THE GROWTH OF MAIZE AFTER WETLAND RICE IN EAST JAVA

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ABSTRACT

Field trials have been carried out in East Java in which maize was grown after paddy rice on two soils. Prior to planting of rice the soil was puddled to different amounts by increasing the number of workings. Animal and tractor draught were also used. After rice the soil was minimum tilled or tilled.

The results showed that yield of maize and other parameters were not influenced by tillage after rice or by animal or tractor draught but by degree of puddling. In a loam soil (Regosol) increased puddling decreased yield while in a clay (Grunosol) increased puddling increased yield.

INTRODUCTION

Maize rates third behind rice and wheat in the world as a cereal. It is an important staple food or a supplement to staple food in South and South-East Asia and is often grown after wetland rice as a second or third crop in a continuous cropping pattern Carangal (1977) and Brontonegoro et al. (1986). The need to increase or maintain food production in these areas is well documented so research into aspects of cereal production is necessary. To obtain high yields good crop establishment is required and this often depends on good seedbed preparation.

In Indonesia land preparation for maize after rice is usually minimum or no tillage and to plant as soon as the soil water content is correct. Maize will rot when planted into saturated or near saturated soils (Brontonegoro et al., 1986), so water content is critical. Storage of available water in the soil for crop use is a requirement in non-irrigated areas. In East Indonesia retaining as much water as possible is important because of the limited extent of the rainy season in some areas and no water is available for irrigation. Crops have been grown on residual soil water in Indonesia and Willatt and Samosir (1984) quote one example in Sulawesi. Syarifuddin and Zandstra (1981) showed that intensive tillage after rice in puddled soils was not justified because the extra energy did not increase yield to cover cost of the extra energy.

Traditional techniques for planting maize include broadcasting the seed in the rice stubble before or just after harvest, dibbling seed into holes made by a planting stick, or planting seeds on to a flat surface and hilling over Brontonegoro et al. (1986). In this experiment soil was prepared by different rates of puddling to grow rice and then planted to maize after the rice was harvested. The soil was prepared for the maize with tillage and minimum tillage techniques at two sites in East Java. Data presented includes yield and some growth parameters.

MATERIALS AND METHODS

The experiments were conducted in 1986 at two locations in East Java; Mojosari 7°30' S; 112°38' E, altitude 30 m ASL, 45 km SW of Surabaya, and at Ngale 7°24'
S; 111°26' E, altitude 50 m ASL, 40 km NW of Madiun. Ngale is on the border between East and Central Java. Both stations are under the management of IMARIF (Malang Research Institute for Food Crops, Agency for Agricultural Research and Development AARD). The two soils differ being a Regosol at Mojosari (loam) and a Grumosol (clay) at Ngale (FAO, 1974). A general description of these rice soils in Indonesia is given by Soepraptohardjo and Suhardjo (1978). At both sites the land had been used for wetland rice for many years particularly in the rainy season, but was sometimes fallow in the dry season.

The sites were puddled prior to growing rice some four months before the maize was grown. There were four puddling treatments:
- PO - no puddling,
- P1 - ploughing and harrowing once with the soil submerged in water,
- P2 - ploughing and harrowing twice with the soil submerged in water,
- P3 - ploughing and harrowing three times with the soil submerged in water.

The ploughing was done with animal drawn implements, oxen or water buffalo, (M1) or with a 2-wheeled tractor (M2) at both sites.

After harvest of the rice, the land was left to dry until it reached the plastic limit water content which is considered satisfactory to produce a good soil tilth (Utomo and Dexter, 1982). Two methods were used to prepare the soil for planting maize, a minimum tillage technique where the surface was worked sufficiently for the seed to be planted at 2 cm (TO) and a tilled treatment where the soil was worked to a depth of 10 cm (T1). In the ploughed treatment large clods were produced which were dried for a week and irrigated to break into smaller clods.

In order to facilitate the mechanical operations two of the four replication of the rice experiment (in each phase) were used for treatment TO and two for treatment T1. There were therefore 8 subtreatments in each of treatments TO and T1 with two replications.

Planting took place when the soil was close to field capacity and was consistent with much planting in East Java in particular but also in a more extensive area in East Indonesia. The maize was planted at Mojosari on 30 April 1986 and at Ngale on 1 September 1986 and harvested on 28 August at Mojosari and 1 December at Ngale. The variety used was Arjuno, a local improved variety in plots 5 x 12 m at Mojosari and 5 x 11 m at Ngale. Two seeds were planted into holes made by a planting stick to a depth of 2 cm and covered with soil. Plant spacing was 80 x 30 cm which gives a final plant population of approximately 42000 plants/ha. Fertilizer application consisted of a basal application of 60 kg N, 40 kg P2O5 and 42 kg K2O/ha, followed by a top dressing of 60 kg N/ha, four weeks after planting. These spacings and fertilizer applications are consistent with practice in Indonesia (Brontonegoro et al., 1986). Weeds were controlled in treatment TO by spraying paraquat (1-1' dimethyl-4, 4'-bipyridylidium ion) at the rate 1 l/ha before seeding. Weeds were removed by hand weeding at three and six weeks after planting. Insect pests were controlled using Furadan 3 G as and when necessary.

After crop establishment plant stand was measured and plants thinned to 240 per plot. This was facilitated by leaving 2 plants in a planting hole where gaps were found i.e. where no seeds germinated or were damaged. Stand count was determined on the basis of dead plants only, non-germinated or insect damaged plants were not included in the stand count or in potential number of plants.

During growth the following plant parameters were measured: plant height at silking, cob length, cob diameter, plant diameter at harvest and grain yield. Just prior to harvest roots were observed to assess whether they were influenced by tillage treatment and will be reported elsewhere.
The data was analyzed using a split-split plot design with tillage and minimum tillage prior to maize the main treatments and type of tillage (animal or tractor) prior to rice the first split with the puddling treatment the second split, Snedecor and Cochran (1968). Degrees of freedom were therefore low for land preparation prior to maize and type of tillage prior to rice, however puddling has a larger number of degrees of freedom requiring a smaller F-values for significance.

RESULTS

Results are given in Tables I and II for percent of dead plants; Tables III and IV plant height; Tables V and VI yield; and Tables VII and VIII statistical significance for all the parameters measured.

TABLE I

Percent dead maize plants/plot 2 weeks after planting - Mojosari.

<table>
<thead>
<tr>
<th></th>
<th>Level of Puddling</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PO</td>
</tr>
<tr>
<td>Animal working (M1)</td>
<td>(TO)</td>
</tr>
<tr>
<td>Tractor working (M2)</td>
<td>(TO)</td>
</tr>
<tr>
<td>Animal working (M1)</td>
<td>(T1)</td>
</tr>
<tr>
<td>Tractor working (M2)</td>
<td>(T1)</td>
</tr>
</tbody>
</table>

TABLE II

Percent dead maize plants/plot 2 weeks after planting - Ngale.

<table>
<thead>
<tr>
<th></th>
<th>Level of Puddling</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PO</td>
</tr>
<tr>
<td>Animal working (M1)</td>
<td>(TO)</td>
</tr>
<tr>
<td>Tractor working (M2)</td>
<td>(TO)</td>
</tr>
<tr>
<td>Animal working (M1)</td>
<td>(T1)</td>
</tr>
<tr>
<td>Tractor working (M2)</td>
<td>(T1)</td>
</tr>
</tbody>
</table>

TABLE III

Plant height of maize at silking in cm - Mojosari

<table>
<thead>
<tr>
<th></th>
<th>Level of Puddling</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PO</td>
</tr>
<tr>
<td>Animal working (M1)</td>
<td>(TO)</td>
</tr>
<tr>
<td>Tractor working (M2)</td>
<td>(TO)</td>
</tr>
<tr>
<td>Animal working (M1)</td>
<td>(T1)</td>
</tr>
<tr>
<td>Tractor working (M2)</td>
<td>(T1)</td>
</tr>
</tbody>
</table>

The treatments which give the most significant differences are the puddled treatments. The not significant parameters for puddling are at Mojosari cob length while at Ngale plant height. The yield is significantly different at both locations for puddled soil, at Mojosari (Regosol) it is the non puddled soil (PO) that is highest while at Ngale (Grumosol) it is the lowest. Similarly for dead plants, at Mojosari puddling increases deaths, (PO) being lowest while at Ngale puddling decreases the number of dead plants the lowest being (P3). Tillage method after rice has no significant effect although whether the land was prepared by tractor (M2) or oxen (M1) for the rice is significant, (M1) having the lower number of plant deaths.
TABLE IV
Plant height of maize at siling in cm - Ngale.

<table>
<thead>
<tr>
<th></th>
<th>Level of Puddling</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PO</td>
</tr>
<tr>
<td>Animal working (M1)</td>
<td>(T1)</td>
</tr>
<tr>
<td>Tractor working (M2)</td>
<td>(T1)</td>
</tr>
<tr>
<td>Animal working (M1)</td>
<td>(T2)</td>
</tr>
<tr>
<td>Tractor working (M2)</td>
<td>(T2)</td>
</tr>
</tbody>
</table>

TABLE V
Yield of maize in t/ha - Mojosari

<table>
<thead>
<tr>
<th></th>
<th>Level of Puddling</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PO</td>
</tr>
<tr>
<td>Animal working (M1)</td>
<td>(TO)</td>
</tr>
<tr>
<td>Tractor working (M2)</td>
<td>(TO)</td>
</tr>
<tr>
<td>Animal working (M1)</td>
<td>(T1)</td>
</tr>
<tr>
<td>Tractor working (M2)</td>
<td>(T1)</td>
</tr>
</tbody>
</table>

TABLE VI
Yield of maize in t/ha - Ngale

<table>
<thead>
<tr>
<th></th>
<th>Level of Puddling</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PO</td>
</tr>
<tr>
<td>Animal working (M1)</td>
<td>(TO)</td>
</tr>
<tr>
<td>Tractor working (M2)</td>
<td>(TO)</td>
</tr>
<tr>
<td>Animal working (M1)</td>
<td>(T1)</td>
</tr>
<tr>
<td>Tractor working (M2)</td>
<td>(T1)</td>
</tr>
</tbody>
</table>

The only parameter showing significance in relation to whether the plots were minimum tilled or tilled after rice was plant height at Ngale, the tilled plots having the taller plants. Plant height was not significant for the other treatments (i.e. puddling and type of ploughing for the rice phase). At Mojosari the effect of type of ploughing for rice and puddling effects plant height (M1) being greater than (M2) which is consistent with lower plant deaths. There was no effect on yield. Yield was influenced by method of land preparation for rice at Ngale. At Ngale yield for (M1) was 3.61 t/ha and just significantly larger at the 5% level than (M2) at 3.25 t/ha. At Mojosari the differences were not significant, however yield was greater for M1 at 4.54 t/ha and for M2 it was 4.25 t/ha.

TABLE VII
Significance levels of statistical analysis of maize at Mojosari 1986.

<table>
<thead>
<tr>
<th>Component</th>
<th>Tillage (T1) vs no Tillage (TO)</th>
<th>Method M1 vs M2</th>
<th>Puddle PO, P1, P2, P3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dead plants</td>
<td>n.s.</td>
<td>1%</td>
<td>1%</td>
</tr>
<tr>
<td>Plant heights</td>
<td>n.s.</td>
<td>1%</td>
<td>1%</td>
</tr>
<tr>
<td>Plant diameter</td>
<td>n.s.</td>
<td>n.s.</td>
<td>1%</td>
</tr>
<tr>
<td>Cob length</td>
<td>n.s.</td>
<td>n.s.</td>
<td>(F = 2.57) n.s.</td>
</tr>
<tr>
<td>Cob diameter</td>
<td>n.s.</td>
<td>n.s.</td>
<td>5%</td>
</tr>
<tr>
<td>Yield</td>
<td>n.s.</td>
<td>n.s.</td>
<td>5%</td>
</tr>
</tbody>
</table>
TABLE VIII
Significance levels for statistical analysis of maize at Ngale - 1986.

<table>
<thead>
<tr>
<th>Component</th>
<th>Tillage (T1) vs no Tillage (T0)</th>
<th>Method M1 vs M2</th>
<th>Puddle PO,P1,P2,P3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dead plants</td>
<td>n.s.</td>
<td>n.s.</td>
<td>5%</td>
</tr>
<tr>
<td>Plant height</td>
<td>1%</td>
<td>n.s.</td>
<td>n.s.</td>
</tr>
<tr>
<td>Plant diameter</td>
<td>n.s.</td>
<td>n.s.</td>
<td>1%</td>
</tr>
<tr>
<td>Cob length</td>
<td>n.s.</td>
<td>n.s.</td>
<td>5%</td>
</tr>
<tr>
<td>Cob diameter</td>
<td>n.s.</td>
<td>n.s.</td>
<td>5%</td>
</tr>
<tr>
<td>Yield</td>
<td>n.s.</td>
<td>5%</td>
<td>1%</td>
</tr>
</tbody>
</table>

DISCUSSION

The most significant effect of all the treatments in these two experiments has been the effect of puddling. This effect is large enough to be still significant after a further working of the soil. It has been said, to attain good structure when taking a soil out of flooded rice production can take up to 3 years. The interesting situation in these soils has been that the one soil is better after pudding and one worse. The texture of the Regosol is a loam with 40% sand, 38% silt and 22% clay while the Grumosol is a clay with 2% sand, 23% silt and 75% clay.

General observations of the soil showed that the Grumosol cracked more readily than the Regosol and the puddled soil (P2 and P3) cracked more and had lower draught (unpublished data) than (P0) and (P1). These factors are important in the Grumosol because at the start of the maize season there was heavy rain and the soil eventually became waterlogged. However in the first period after rain where the seedlings were small and therefore more vulnerable to waterlogging (Brontonegoro et al., 1986) the greater cracking (P2) and (P3) would assist drainage. The reason for the greater cracking in this soil is related to the high montmorillonite clay content and greater mixing (or puddling) usually orients the clay plates more uniformly. This greater uniformity will lead to greater cracking and these aggregates tend to be very stable in water (Emerson, 1967). Good early growth and better soil structure also given the maize in the puddled treatments in this soil a yield advantage.

In the Regosol greater mixing (puddling) will usually result in a higher density. Higher density soils usually have higher penetration resistance at the same water content and also draught at ploughing. At Mojosari the draught was higher and penetration resistance, measured at Mojosari 25 days after planting at 5 cm with a 2 cm diameter probe two weeks after the first irrigation, was greater with puddling (P3) (unpublished data). Soil resistance was greater with (M2) than with (M1) and finally (TO) has greater resistance than (T1). When this data is correlated with yield, yield increased with decrease in penetration resistance, the regression equations were \( Y = 8.0 - 0.085X \) \( r = -0.84 \) for Mojosari and \( Y = 5.0 - 0.052X \) \( r = -0.67 \) for Ngale. Maize yields are known to decrease with increase in soil penetration resistance Kayombo and Lal (1986).

At Mojosari and Ngale the two experiments have highlighted an important fact in relation to tillage experiments. In this case the soil preparation treatments, the maize variety used, fertilizer applications and general agronomy were the same, irrigation water was available to ensure good growth, the climate i.e. temperature and seasonal factors (apart from rainfall times) were also similar, the major difference was the soil. Tillage experiments often give conflicting results as soil type changes which makes general recommendations difficult and because of this technology is not always directly transferable (Lal, 1985).
In the context of Indonesia agriculture (particularly in east Indonesia) where dryland crops are grown after wetland rice it would appear that the present recommendation of minimum tillage is satisfactory because yield is not affected by tillage prior to planting maize. The yields are significantly influenced however by the treatment given to the rice. It is not the object of this paper to talk about rice yields, but the degree of puddling influenced rice yield and increased yield to a certain extent in both soils (unpublished data). The difference between treatments (M2) and (M1) for rice yields was variable. It would appear that the land system used by the Indonesian (Javanese) farmer which has evolved over time is suitable to local weather conditions and soils. The need to change the system is not advocated from these experiments and there appears to be no advantage in yield from tractor driven implements. However no work is being carried out at MARIF on land preparation (Brontonegoro et al., 1986).

A final point Brontonegoro et al. (1986) presented data which indicates that yield potential of the maize variety Arjuna is 5.0 to 6.0 t/ha. At the Mojosari experiment yields ranged from 3.2 to 5.4 t/ha (Table 5) while at Ngale the range was 2.2 to 4.1 t/ha (Table 6). These yields tend to reach the yield potential. It also showed the in Ngale and Mojosari districts the yield average was 1.0 - 1.5 t/ha.

REFERENCES


Pedotechnique: Soil Classification, Soil Mechanics and Soil Handling

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Abstract

Pedotechnique is an interdisciplinary science which tries to integrate research results from various disciplines of soil science into all-embracing concepts (models) of the dominant processes which, in the various soils, determine the effect of soil handling on the resultant soil qualities. Pedotechnical interpretation of soil maps, complemented with relevant field and laboratory determinations, is needed to obtain data on soil mechanical properties required to predict the soil’s mechanical behaviour during soil handling.

This paper is also a plea for recognition of the Working Group PT (Pedotechnique) of the International Society of Soil Science (ISSS), for its objectives, and for its willingness to cooperate with specialist groups within the International Soil Tillage Research Organization (ISTRO) and similar organizations who cover important parts of the broad field of work of Working Group PT.

Introduction

In the Netherlands, basic information about the soil profile to a depth of 1.20 m may be derived from the soil map on a scale of 1:50,000, on which also the mean depths of the highest and the lowest groundwater table are indicated. This soil map, or soil maps on larger scales (1:10,000 or 1:5,000), is instrumental in the planning of urban and regional development and, to some degree, provides information on soil suitability for agriculture and forestry or for the ceramic industry. However, questions concerning the effect of soil handling on soil quality, whether in superficial layers as in harrowing or ploughing, or in deeper layers as in subsoiling or open-cast mining, remain largely unanswered. The same applies to the effect of field traffic on the ploughed layer and on the subsoil. Generally, it can be stated that the relationship between qualitative pedological soil characteristics and quantitative mechanical soil properties and their effect on the course of mechanical soil processes and the resulting soil qualities is largely unknown.

The new discipline within soil science, pedotechnique, tries to establish these relationships, aiming at prediction of the effect of mechanical soil loading by all kinds of soil-
engaging equipment including wheels and other running gear. Pedotechnique may be regarded as the link between pedology and engineering (Wilson and Van Ouwerkerk, 1987). Pedotechnique focuses on the unsaturated structured pedon (0-120 cm depth), whereas geotechnique (foundation engineering; classical soil mechanics) generally pertains to saturated, unstructured deeper layers of the earth's crust. Pedotechnique usually considers the structured soil as a "whole body", which has to be handled in situ, as in agriculture, horticulture and forestry. However, the structured soil may also be regarded as a raw material which has to be processed elsewhere, as in the ceramic industry, or has to be removed temporarily and subsequently restored, as in open-cast mining. A supplementary poster paper (Koolen and Van Ouwerkerk, 1988) gives more detailed information on the scientific content of pedotechnique.

PEDOTECHNIQUE

Pedotechnique may be subdivided into three parts: 1) soil map interpretation, 2) soil mechanics and related processes, and 3) prediction of the effects of the application of mechanical stresses in soil handling techniques. Through pedotechnical interpretation of soil maps it is attempted to establish for each soil series the soil properties which may be regarded as characteristic of its mechanical behaviour under external loading. Such properties are cohesion, angle of internal friction, shear strength, breaking force, compaction, etc. (Koolen and Van Ouwerkerk, 1988). However, within each soil series a wide range of values may occur, due to the effects of different soil management practices.

Most of the soil mechanical properties mentioned above are neither contained in the soil map, nor in the accompanying books, such as "Soil map of the Netherlands on a scale of 1:50,000. Comments on sheet X" (cf. Stiboka, 1987). However, data are presented that relate to soil mechanical characteristics, such as soil texture, structure, organic matter content, etc. Pedologists should be asked to expand their field observations with at least determinations of bulk density, moisture retention characteristics, and simple soil mechanical properties such as cone index. A fine early example of this highly desirable kind of soil mapping may be found in Swedish work (Andersson and Håkansson, 1963). Recent examples are available from England (Jarvis and Mackney, 1979; Hodge et al., 1984) and Canada (Wilson, 1985). It should be stressed that soil maps on a scale of 1:50,000 are only available in densely populated, "rich" countries, such as The Netherlands. In vast areas of the world even soil maps on a scale of 1,000,000 are still unattainable luxuries.

The central part of pedotechnique, "pure" soil mechanics, has made much headway in recent years (Koolen and Kuipers, 1983) and, therefore, by now the processes and the forces involved are much better understood than 10 years ago (Koolen, 1978; Kowenhowen, 1979). Also the effects of these processes on the resulting soil qualities are better known (Beekman, 1987; Tijink, 1988). Understandably, however, basic research in this domain has been limited mainly to a small number of selected soils, and has usually been conducted under
laboratory conditions. Therefore, there is a pressing need to expand this basic research to include many more soil types as well as field situations.

In view of the developments described above, chances of modeling soil mechanical behaviour during tillage and soil handling in general, and of predicting the effects of soil handling on soil qualities now seem to become realistic. Attempts have been made to develop models that predict effects of tillage on soil hydraulic properties, bulk density and mechanical impedance, soil temperature and thermal conductivity, aeration, water infiltration and evaporation from the soil (Kral, 1982). However, even good models require accurate input data and precisely these data are usually lacking (Driessen, 1988). In our view, the required standardization and degree of accuracy can only be obtained by close international cooperation between the relatively few researchers working in this field.

ISSS WORKING GROUP PT (PEDOTECHNIQUE)

The Working Group Pedotechnique (PT) of Commission VI (Soil Technology) of the International Society of Soil Science (ISSS) provides the forum for international cooperation between pedologists, researchers in soil mechanics, and specialists in soil handling. The aim is pedotechnical interpretation of soil maps and, therefore, cooperation with ISSS Commission V (Soil Genesis, Classification and Cartography) is desirable. Soil handling influences the resultant soil qualities, which have to satisfy demands of trafficability and workability, but also of plant growth. It is therefore desirable to keep in touch with ISSS Commission I (Soil Physics). In view of the large spatial and temporal variability of soil structure, it is obviously desirable to cooperate closely with ISSS Commission I Working Group MV (Soil and Moisture Variability in Time and Space). Finally, it should be stressed that Working Group PT (W.G. PT) has interests in common with ISSS Commission VI Working Group LI (Land Evaluation Information Systems). Therefore, close cooperation between Working Groups PT and LI should be established.

On the initiative of its present Chairman, ISTRO member Dr. G. Wilson (Ottawa, Canada), ISSS Working Group Pedotechnique was founded in 1982 during the 12th International Congress of ISSS, New Delhi, India. It made its first public appearance in 1986 at the 13th International Congress of ISSS, Hamburg, Federal Republic of Germany, with a Symposium, "Pedotechnical Interpretations of Soil Surveys for Tillage and Compaction" (Van Ouwerkerk, 1987b). The papers presented there considered fundamental soil mechanics, soil susceptibility to compaction, land evaluation and classification related to soil compaction and soil tillage, and the relationship between pedotechnology and soil tillage research. These papers were edited by the present Secretary of W.G. PT, Ir. G. van Ouwerkerk, and were subsequently published in a Special Issue of Soil & Tillage Research (Vol. 10/1, September 1987), entitled "Pedotechnique".
ISTRO

The relationship between ISTRO and W.G. PT lies in the fact that soil tillage is an integral part of soil management which, in turn, is within the scope of W.G. PT. Therefore, W.G. PT is neither a competitor to ISTRO, nor vice versa. In our opinion, all people working in any discipline of soil science should be members of ISSS which, with about 9000 members world-wide and embracing all disciplines within soil science, is internationally recognised as the prime professional soil scientists' organisation. On the other hand, ISTRO, with about 450 members, is an organisation of specialists in soil tillage research, although this is such a broad field that, also within ISTRO, Working Groups focusing on narrower subjects will be established. However, the scope of W.G. PT is wider than any of the present and future ISTRO Working Groups.

W.G. PT is well aware that among ISTRO members several specialists could make valuable contributions to W.G. PT, but only on the basis of their affiliation with ISTRO. Thus, members of ISTRO Working Groups A (Tillage Related Soil Physical Properties) and B (Soil Compaction by Vehicles of High Axle Load) would be very welcome to join W.G. PT as advisers. Likewise, it may be expected that several members of the International Society for Terrain-Vehicle Systems (ISTVS) will be interested in membership in W.G. PT, although this organisation is primarily concerned with off-the-road locomotion, vehicle construction and performance.

HANNOVER/ST.PAUL WORKSHOP GROUP

The same interest in the activities of W.G. PT may be expected from the international group of research workers who assembled in August 1986 in Hannover (Federal Republic of Germany) in the 1st International Workshop on Soil Physics and Soil Mechanics, "Interaction of Structured Soil with Water and External Forces" (Van Ouwerkerk, 1987a). The objective of this workshop was to discuss interdisciplinary work in soil physics and soil mechanics, the process of soil structure formation, and the impact of water and external forces on differently structured soils (Drescher et al., 1988). This group will hold their second meeting, "International Workshop on Mechanics and Related Processes in Structured Agricultural Soils", in September 1988 in St. Paul (MN, U.S.A.). The activities of these research workers coincide with the principal field of work of W.G. PT. However, as they do not have their own permanent organisation, they could well become the "hard core" of W.G. PT. As stated above, the mechanics of structured agricultural soils may be regarded as the theoretical cornerstone of pedotechnique.

THE FUTURE

In 1990, Working Group PT will organise a Symposium, "Pedotechnical Approaches to Present-Day Soil Handling and
Field Traffic Problems", at the 14th International Congress of ISSS, Kyoto, Japan. We expect that many ISTRO members (who are hopefully also ISSS and W.G. PT members) will be present and will make contributions in the form of papers and poster presentations. In the meantime, W.G. PT will try to execute several items of its Plan of Action (Van Ouwerkerk, 1987b), which includes an inventory of field and laboratory methods used to describe and determine soil parameters related to soil mechanical behaviour, measurement of soil behaviour during tillage and field traffic in relation to soil mechanical properties, and exchange of relevant literature on pedotechnique.

REFERENCES


SOME CHARACTERISTICS OF SOIL TILLAGE FOR MAIZE IN THE MAIN MAIZE GROWING REGIONS OF YUGOSLAVIA

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ABSTRACT

Tillage systems used for maize in the main regions of Yugoslavia are characterized by a great number of working operations. This results in the waste of fuel, loss of time and compaction of the soil. Soil is commonly compacted during seedbed preparation, which greatly reduces the effect of autumn ploughing.

Studies in this field have lead to the so-called conventional soil tillage for maize. Consequently separate machines have been developed for soil tillage, fertilizer application, herbicide application, herbicide incorporation, planting and cultivation. This does not allow connecting several operations into one, although such work is considerably more expensive than other more rational soil tillage systems in Western Europe and the United States.

The purpose of this paper is to present soil tillage systems for maize in Yugoslavia, to offer a survey of relevant literature and to indicate the feasibility of a more rational soil tillage system for maize.

INTRODUCTION

Maize is the major field crop in Yugoslavia. In 1986 total maize production was 12,526,000 tons on 2,369,000 hectares, with an average yield of 5.28 t ha⁻¹. In view of favourable environmental conditions for maize production, yields could be higher. Maize production is affected by many factors. One of the most important is the fact that state-owned farms, total areas under maize, whereas private farms, with an average yield of 4.96 t ha⁻¹, take up 72% of total areas under maize (1986). Soil tillage in the private sector is mainly based on traditions and experiences of the farmers, often including inadequate cultural practices.

The conventional maize growing system is commonly used on state farms. It comprises a great number of working operations, which makes it expensive. This imposes the need to investigate the possibilities of using a more rational maize growing system. Such policy entails the development or import of direct planting machinery.

Our ten-year experiments showed that growing maize without
soil tillage on chernozem is feasible without significantly reducing yield.

The primary objective of the present investigation was to identify the essential working operations in the conventional maize growing system and to propose a more rational version for the environments of the major maize growing regions in Yugoslavia.

MATERIALS AND METHODS

Studies were conducted in Vojvodina. This is the most important region for maize production in Yugoslavia. In 1986 maize was grown here on 737,000 ha. The average yield was 6.99 t ha\(^{-1}\). A total of 5,181,000 t were produced, or 41% of Yugoslav maize production.

In order to determine the number of working operations performed in maize production, we studied the maize production system on eight agricultural combines (large state farms) in 1986 and 1987. These combines annually produce maize on approximately 20,000 ha. The average yield for the investigated period was 8.2 t ha\(^{-1}\). The number of working operations in maize production is similar on other combines and on a small number of private farms in Yugoslavia.

A trial with minimum and conventional soil tillage was conducted in Zemun Polje from 1978 to 1987. The minimum tillage treatment included the following five working operations: fertilizer application, herbicide application, planting, cultivation and harvest. The conventional tillage treatment comprised eight working operations: stubble field shallow ploughing to 15 cm, fertilizer application, ploughing to 25 cm, seedbed preparation, herbicide incorporation, planting, cultivation and harvest.

Studies were carried out on the chernozem type of soil. In Yugoslavia this type of soil accounts for 5.7% (1,453,000 ha) of total arable land. These areas are largely planted to maize. The 0-40 cm chernozem layer contains 38.2% clay, 2.3% sand and 59.5% silt, 3.5% humus, N 0.17%, P\(_2\)O\(_5\) 25.1 mg/100 g soil, K\(_2\)O 25.2 mg/100 g soil. The pH values in water and KCl were 7.7 and 7.2, respectively.

The preceding crop in all years was wheat. Fertilizer was applied in autumn: N 150 kg ha\(^{-1}\), P\(_2\)O\(_5\) 105 kg ha\(^{-1}\) and K\(_2\)O 75 kg ha\(^{-1}\). Maize hybrid ZPSC 1A was grown from 1978 to 1984 (40,800 plants ha\(^{-1}\)). Subsequently, hybrid ZPSC 704 was grown from 1985 to 1987 at a density of 59,500 plants ha\(^{-1}\). Planting was done around 20 April and harvest around 10 October, varying with environmental conditions of the year. In the minimum tillage treatment total herbicide Gramoxon (200 g/l paraquat) was used at a rate of 6 l ha\(^{-1}\) ten days before planting. In the conventional tillage treatment Lasso-Atrazine herbicide (alachlor 48% and atrazine 50%) was applied at the same rate.
CLIMATIC CHARACTERISTICS

Basic meteorological data for the last three years of investigation during the growing season (Table I) showed variations. Mean air temperatures ranged from 18.2°C in 1985 to 18.7°C in 1986 and 1987. The lowest rainfall during the growing season was in 1985 (302.2 mm) and the highest in 1987 (410.6 mm). The distribution of precipitation was very different from year to year, so the conditions for maize growing were not the same. Drought occurred in July 1985 and August and September 1986. Climatic conditions in some other parts of Vojvodina were even less favourable.

Table I

Mean monthly air temperature and total rainfall during the growing season in Zemun Polje.

<table>
<thead>
<tr>
<th>Climatic factor</th>
<th>Year</th>
<th>A</th>
<th>M</th>
<th>J</th>
<th>J</th>
<th>A</th>
<th>S</th>
<th>Average</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature °C</td>
<td>1985</td>
<td>12.0</td>
<td>18.6</td>
<td>17.7</td>
<td>21.5</td>
<td>22.3</td>
<td>17.4</td>
<td>18.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1986</td>
<td>14.6</td>
<td>19.0</td>
<td>19.9</td>
<td>22.4</td>
<td>16.9</td>
<td>18.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1987</td>
<td>11.5</td>
<td>15.6</td>
<td>20.7</td>
<td>24.1</td>
<td>20.3</td>
<td>20.2</td>
<td>18.7</td>
<td></td>
</tr>
<tr>
<td>Rainfall mm</td>
<td>1985</td>
<td>58.6</td>
<td>28.7</td>
<td>125.7</td>
<td>17.2</td>
<td>126.1</td>
<td>10.0</td>
<td>366.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1986</td>
<td>74.9</td>
<td>53.3</td>
<td>84.1</td>
<td>73.2</td>
<td>13.0</td>
<td>3.7</td>
<td>302.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1987</td>
<td>57.9</td>
<td>164.4</td>
<td>73.1</td>
<td>62.3</td>
<td>46.3</td>
<td>6.6</td>
<td>410.6</td>
<td></td>
</tr>
</tbody>
</table>

RESULTS AND DISCUSSION

Studies of the conventional maize growing system on selected state farms in Vojvodina in 1986 and 1987 demonstrated that 10 to 16 working operations are performed. More operations are carried out in spring during seedbed preparation, thus causing unnecessary compaction of the surface soil layer. Similar studies were conducted in Romania (Chanarache, 1987). In the past the number of working operations was higher and tillage deeper (Drezgić, 1979). The number of passes often depends on climatic conditions, which results in the varying number of cultivations needed in different years. However, data (Table II) indicate that there are working operations which could be omitted without reducing yield. Such a system of maize growing is related to agricultural machinery, whose development was directed towards conventional maize production. Machines used for such a tillage system are becoming increasingly heavy. It is for this reason that on some combines the number of passes in maize production was reduced. For example, fertilizer is applied in one pass in autumn, two to three herbicide combinations are applied in one pass, cultivation and side dressing are omitted whenever possible. This gradually leads to more rational maize production. Nevertheless, this does not yet meet the requirements of saving time and energy, reducing soil compaction and, also very important, reducing the costs of
maize production.

In our ten-year experiments average yield of maize grown without soil tillage and under conventional tillage was 9.75 and 10.84 t ha\(^{-1}\), respectively (Fig. 1). The latter outyielded the former by 1.09 t ha\(^{-1}\) or 10.06\%. This shows that minimum tillage can be used without major yield reductions on soil with good physical and chemical properties, such as chernozem. It is interesting that in years with insufficient rainfall in July and/or August (1985) yield was the same in the treatments investigated (8.23 and 8.29 t ha\(^{-1}\), respectively). This means that fluctuations in grain yield from season to season are attributed to the variations in rainfall and other related biological factors. Žugec (1986) found that conventional soil tillage on pseudogley and chernozem provided the highest yield in Slavonia (Yugoslavia).

For the conditions of southern Nigeria (Lal, 1982) no-till gives higher yield than conventional methods of seedbed preparation. Similar results were obtained in other parts of the world (Vyn et al., 1982; Anderson, 1986).

Studies of maize growing systems on agricultural combines in Yugoslavia and long-range experiments with soil tillage indicated possibilities to reduce the number of passes and thus achieve beneficial effects. On the basis of these results we propose a more rational maize growing model for light soils and those that have good physical and chemical properties (Table II). The proposed model enables cultural practices even with the existing machinery. This model includes the following working operations: application of the entire amount of fertilizer in October, primary soil tillage to 25 cm in October, herbicide incorporation and seedbed preparation around 10 April, planting around 20 April and harvest in early October. The number of working operations would thus total five, although one cultivation with side dressing could be used if necessary. The same or similar maize growing system can be applied on soil with slightly heavier physical and chemical properties following adequate and timely primary soil tillage in autumn. This would be a much more rational method of growing maize and could also represent a transitory phase towards introducing minimum soil tillage in the main maize growing regions of Yugoslavia. For the environments of the USA Allmaras and Dowdy (1985) proposed nine tillage management regions.

CONCLUSIONS

Studies of the conventional maize growing system on agricultural combines and long-range experiments in Yugoslavia indicated the following:

Conventional soil tillage includes 10 to 16 working operations. Some of them can be omitted or performed in one pass. It is possible to avoid three to four working
Table II

Working operations in maize production on state farms in Yugoslavia.

<table>
<thead>
<tr>
<th>Working operation</th>
<th>Time</th>
<th>Number of passes</th>
<th>Proposed model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fertilizer application</td>
<td>July/Aug</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Shallow ploughing</td>
<td>July/Aug</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Deep ploughing</td>
<td>October</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Fertilizer application</td>
<td>April</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td>Seedbed preparation</td>
<td>April</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Herbicide incorporation</td>
<td>April</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Planting</td>
<td>April</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Herbicide application</td>
<td>April</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Side dressing and/or</td>
<td>May</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>cultivation</td>
<td>October</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

**Total** 10 16 5/6

Fig. 1. Effect of soil tillage on maize yield in Zemun Polje (Yugoslavia).
operations without reducing maize yield.

In experiments conducted over ten years maize yield on chernozem decreased by 1.09 t ha\(^{-1}\) or 10.06\% under minimum tillage compared to conventional tillage.

The proposed model of a more rational maize growing system includes five working operations: fertilizer application, primary soil tillage in autumn to 25 cm, herbicide incorporation and seedbed preparation in one pass, and harvest. If necessary, cultivation with side dressing can be applied.

REFERENCES


CROP SEQUENCE AND CONSERVATION TILLAGE EFFECTS ON SOIL STRUCTURE AND MAIZE GROWTH

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ABSTRACT

Field studies were undertaken on three soil types to assess the interaction effects of five previous crops and three tillage systems on soil physical structure and maize (Zea mays L.) growth response. Maize was planted with three tillage systems (based on fall moldboard plowing, fall chisel plowing, and zero tillage) imposed after a single year’s production of five previous crops: maize, barley (Hordeum vulgare L.), red clover (Trifolium pratense L.), soybeans (Glycine max L.) and an alfalfa/timothy mixture (Medicago sativa L. and Phleum pratense L.). Of the seven 2-year studies involved, three experiments were conducted on a well drained loam soil (1983 to 1986), two on an imperfectly drained silt loam soil (1983 to 1985) and two on a poorly drained clay loam soil (1984 to 1986). Previous crop x tillage system interactions were non-significant for the measurements of soil structural properties such as aggregate size distribution, aggregate stability and bulk density on all three soil types. Significant previous crop x tillage system interactions were observed for maize growth and development rates on the loam soil, as well as for maize grain yields on the loam and clay loam soils. On the latter two soil types maize yield reductions with zero tillage, relative to conventional tillage, were greatest following red clover and least following either soybeans or alfalfa/timothy.

INTRODUCTION

Although many studies have been conducted to monitor the effects of various tillage systems on soil structural properties and on the productivity of maize and other grain crops, there has been insufficient research to investigate the relative effects of conservation and conventional tillage systems when maize is grown in rotation with crops other than grain crops (eg. forages). A limited amount of research in the central Corn Belt States of the United States has demonstrated that yield reductions with zero tillage, relative to conventional tillage (moldboard plowing), on poorly drained soils are significant with continuous maize production but insignificant when maize follows soybeans (Dick and Van Doren, 1985; Kladivko et al., 1986; Erbach, 1982). Significant interactions of crop rotation and tillage system for maize yield have not been observed on well-drained soils in this region, where maize yields have been similar for zero and conventional tillage even when maize follows maize (Griffith et al., 1973; Eckert, 1984).

In Ontario, average maize yields have been 12% and 7% lower following zero tillage and chisel plowing, respectively, than with conventional tillage when maize is grown continuously on medium- and fine-textured soils (Vyn et al., 1982). Preliminary research in the early 1970’s indicated that maize yield reductions with zero tillage may
be less evident when maize follows alfalfa rather than maize (Vyn et al., 1979). Further adoption of conservation tillage systems for maize production in Ontario is at least partially dependent on a better understanding of the response of maize to tillage systems when maize follows various crops in rotation. Since certain soil physical properties may be partially responsible for maize growth and yield reductions with conservation tillage systems (Vyn et al., 1982), greater insight into the combined impacts of crop sequence and tillage systems on soil physical structure would also be beneficial.

The central objective of this research was to determine the interaction effects of five previous crops and three tillage systems on soil physical structure and maize growth, development and yield.

MATERIALS AND METHODS

Series of 2-year crop sequence experiments were established at three locations in Southern Ontario. These experiments were initiated on a well drained loam soil near Woodstock and on an imperfectly drained silt loam soil near Elora in 1983, while a trial on a poorly drained clay loam soil near Salford was initiated in 1984. Each of the sites was tile drained and had been planted to maize prior to the beginning of the experiment. The silt loam and clay loam sites involved two series of 2-year crop sequence trials; the loam site involved three series. The first-year rotation component included maize, barley, red clover, soybeans and an alfalfa/timothy mixture while maize was planted on the entire area in the second year.

The experiments at each location were established with a randomized block split plot experimental design with four replications. During the late fall of the first year of each 2-year sequence, tillage treatments were assigned randomly to subplots within each main plot. The three tillage treatments for the second-year maize were:

(i) Zero tillage, with spring chemical kill of the red clover and alfalfa/timothy plots
(ii) Fall moldboard plow to depth of 20 cm, plus two passes of field cultivator
(iii) Fall disk-chisel plow to depth of 15 cm, plus secondary tillage as for (ii)

When maize was planted in the spring following the five previous crops, the tillage sub-plots were further split into two sub-sub plots with different levels of surface residue cover in the row area. Due to limited space, all tillage results presented below represent an average of the two sub-sub treatments. A total of 163 kg ha⁻¹ of actual N was applied to the maize crop in the second year of each series.

Soil samples for aggregate size and wet aggregate stability (Yoder) were taken immediately after planting maize, while bulk density was measured approximately one month after planting. Corn growth and development was monitored by periodic measurements of height, leaf number, leaf area and flowering date while grain yields were obtained after physiological maturity.
RESULTS AND DISCUSSION

1. Soil Structural Properties

Analysis of the measurements of the soil physical properties across years at each location indicated that there were no significant previous crop x tillage system interactions. However, significant differences were apparent in the main effects of previous crop and/or tillage systems at each location.

The size distribution of soil aggregates in the surface 7 cm after planting maize was significantly affected by tillage treatments on all three soil types (Table 1). Lowest proportions of fine aggregates were observed with zero tillage, while no significant differences were encountered between the moldboard and chisel plow treatments. On the loam and silt loam sites, soil from the seedbed zone of plots which were previously in corn tended to have a lower proportion of fine aggregates.

Table I. Effect of previous crop and tillage system on soil aggregate size distribution.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Previous crop</td>
<td>Maize</td>
<td>53.0 c</td>
<td>57.7 b</td>
<td>47.8 a</td>
</tr>
<tr>
<td></td>
<td>Barley</td>
<td>55.7 bc</td>
<td>60.3 ab</td>
<td>46.5 a</td>
</tr>
<tr>
<td></td>
<td>Red clover</td>
<td>60.7 a</td>
<td>63.9 ab</td>
<td>42.2 a</td>
</tr>
<tr>
<td></td>
<td>Soybeans</td>
<td>56.6 abc</td>
<td>63.2 ab</td>
<td>41.1 a</td>
</tr>
<tr>
<td></td>
<td>Alfalfa/timothy</td>
<td>58.2 ab</td>
<td>64.1 a</td>
<td>41.0 a</td>
</tr>
<tr>
<td>Tillage</td>
<td>Zero</td>
<td>46.4 b</td>
<td>56.8 b</td>
<td>37.1 b</td>
</tr>
<tr>
<td></td>
<td>Moldboard</td>
<td>62.7 a</td>
<td>65.8 a</td>
<td>48.8 a</td>
</tr>
<tr>
<td></td>
<td>Chisel</td>
<td>61.4 a</td>
<td>62.9 ab</td>
<td>45.2 ab</td>
</tr>
</tbody>
</table>

* Within effect means followed by the same letter are not significantly different at the 5% level.

The water stability of soil aggregates was higher with zero tillage than conventional tillage on the loam and clay loam sites, but not on the silt loam soil (Table II). The general improvement in structural stability noted for zero tillage was consistent over all five previous crops. Soybeans resulted in significantly lower aggregate stability than maize on the loam and silt loam soils. A single year of red clover or alfalfa/timothy did not improve the stability of surface soils at any of the sites. Longer-term meadow crops might have been associated with an improvement in soil aggregate stability, relative to continuous maize production.

Although bulk density values were not affected by previous crops in rotation, bulk density in the surface layer of soil was significantly affected by tillage systems at all three locations (data not shown). Zero tillage resulted in consistently higher soil density than either moldboard or chisel plowing.
Table II. Effect of previous crop and tillage treatments on wet aggregate stability in the seedbed zone.

<table>
<thead>
<tr>
<th>Effect</th>
<th>Level</th>
<th>Aggregate stability (%)*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Loam</td>
<td>Silt loam</td>
</tr>
<tr>
<td>Previous crop</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corn</td>
<td>62.1 a**</td>
<td>49.8 a</td>
</tr>
<tr>
<td>Barley</td>
<td>61.6 a</td>
<td>45.8 c</td>
</tr>
<tr>
<td>Red clover</td>
<td>59.5 a</td>
<td>47.1 abc</td>
</tr>
<tr>
<td>Soybeans</td>
<td>55.4 b</td>
<td>46.7 bc</td>
</tr>
<tr>
<td>Alfalfa/timothy</td>
<td>58.8 ab</td>
<td>49.0 ab</td>
</tr>
<tr>
<td>Tillage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zero</td>
<td>63.0 a</td>
<td>48.3 a</td>
</tr>
<tr>
<td>Moldboard</td>
<td>57.0 b</td>
<td>48.0 a</td>
</tr>
<tr>
<td>Chisel</td>
<td>58.5 ab</td>
<td>46.8 a</td>
</tr>
</tbody>
</table>

* Wet stability determined only on 1 to 2 mm diameter aggregates.
** Within effect means followed by the same letter are not significantly different at the 5% level.

2. Maize growth, development and yield

At about 5 weeks after planting, corn plants were shorter and had fewer emerged leaves in the zero-till system than with conventional tillage on all three soil types. Significant previous crop x tillage system interactions were observed for all pre-harvest measurements on loam soil, only for silk emergence rate on silt loam soil, and not at all on clay loam soil. On the loam soil, maize plant heights and leaf numbers were not significantly lower with zero tillage when maize followed soybeans rather than the other previous crops (Table III).

Table III. Previous crop by tillage system interactions for plant height and leaf number of maize plants on loam soil (average of 1984-86).

<table>
<thead>
<tr>
<th>Previous crop</th>
<th>Plant height (cm)</th>
<th>Leaf number</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Zero Moldboard Chisel</td>
<td>Zero Moldboard Chisel</td>
</tr>
<tr>
<td>Maize</td>
<td>30.1 32.9 32.4</td>
<td>6.3 6.9 6.8</td>
</tr>
<tr>
<td>Barley</td>
<td>30.7 32.7 32.7</td>
<td>6.5 6.9 6.9</td>
</tr>
<tr>
<td>Red clover</td>
<td>27.7 32.0 31.3</td>
<td>6.3 7.0 6.8</td>
</tr>
<tr>
<td>Soybeans</td>
<td>30.6 31.9 31.9</td>
<td>6.7 6.9 6.9</td>
</tr>
<tr>
<td>Alfalfa/timothy</td>
<td>26.0 31.0 32.0</td>
<td>5.9 6.8 6.8</td>
</tr>
</tbody>
</table>

LSD (0.05) = 1.9    LSD (0.05) = 0.2

Silk emergence was significantly delayed for zero tillage, relative to moldboard plowing, on all three soils. Examination of the significant interactions of previous crop and tillage on the loam and silt loam soils suggested that greater delays (an additional 1 to 2 days) in silk emergence were encountered in zero-till plots after red clover and alfalfa/timothy than after other previous crops (data not shown). Maize leaf areas after mid silking were significantly lower with zero tillage than with moldboard plowing, except when maize followed either barley or soybeans on the loam soil.
Maize grain yields on loam soil (Figure 1) were from 6 to 11% higher when maize was planted in rotation rather than following maize. Although corn yields with zero tillage are approximately 8% lower than those after moldboard or chisel plowing, the presence of a significant previous crop \times \text{tillage} \text{system interaction demonstrates that this reduction varies with previous crop in rotation. Indeed, the reduction in yield with zero tillage was insignificant following soybeans and greatest following red clover.} \[
\text{LSD (0.05) = 0.29 (crop), 0.39 (tillage)}
\]

Maize yield response to previous crops in rotation on silt loam soil was similar to that on the loam soil (Figure 2). Maize yields were from 8 to 12% higher when maize was planted in rotation. However, tillage treatments did not have a significant effect on maize yields and, furthermore, there were no significant interactions. \[
\text{LSD (0.05) = 0.55 (crop), 0.38 (tillage)}
\]

On the clay loam soil, maize yields were from 6 to 8% higher following barley, soybeans or alfalfa/timothy than following maize (Figure 3). Maize yields, on average, were 7% lower with zero tillage than with moldboard plowing; this yield reduction was significant among all previous crops but alfalfa/timothy, where the differences were insignificant. The large yield reductions with zero tillage which were apparent on both the loam and clay loam soils when maize followed red clover was primarily due to insect damage and lower plant density with this treatment in 1986.
CONCLUSIONS

1. Soil structural properties were affected more by tillage systems than by previous crop treatments.
2. Previous crop x tillage system interactions were insignificant for the soil structural properties measured.
3. Previous crop x tillage system interactions were significant for early corn growth and development only on the loam soil.
4. Corn grain yields increased when corn was grown in rotation with crops other than corn on all three soil types.
5. Significant previous crop x tillage system interactions for grain yields were apparent on the well drained loam soil as well as on the poorly drained clay loam soil.

REFERENCES

MANAGING CROP RESIDUE AND TILLAGE PANS FOR PEA PRODUCTION

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\textsuperscript{2}USDA-ARS, Pacific West Area, Prosser, Washington

ABSTRACT

Paraplow tillage 33 to 38 cm deep in medium textured Haploxeroll soils on slopes of less than 13\% in eastern Washington and Oregon, USA, fractured tillage pans that had developed over 25 years, but the pans reformed rapidly. In 20 months the pans had reformed to almost their original state before deep tillage. Paraplow\textsuperscript{3} tillage did not significantly change the amount of soil water stored in the profile, soil water extraction patterns, stand establishment, pea biomass or fresh pea yield.

Leaving less than 30\% of the soil covered with crop residue by chisel plowing for soil and water conservation did not significantly influence soil temperature, soil water content, pea stands, biomass or fresh pea yield as compared to leaving less than 5\% ground cover with moldboard plowing.

INTRODUCTION

Soil compaction and residue management are of primary concern in the fresh pea (\textit{Pisum sativum} L.) production area of eastern Washington and Oregon, USA. In this region peas have been grown in rotation with cereals, primarily wheat (\textit{Triticum aestivum} L.) for over 25 years. There is a high potential for the formation of tillage and traffic pans in this area because of the extensive use of large wheel tractors and tilling the soil at high water contents. The soils in this region are highly productive but are also highly erodible. Placing crop residue on and near the surface of these soils has a high potential for conserving soil and water.

Peas are sensitive to soil compaction (Voorhees et al., 1975; Whiteley and Dexter, 1982), but Wilkins et al. (1986) have shown that fracturing tillage pans in the Pacific Northwest of USA in 1986 by Paraplow tillage did not increase pea or wheat yields.

The objectives of this research were to determine the effectiveness of paraplow tillage to fracture the tillage pan and the influence of crop residue management on pea yield.

MATERIALS AND METHODS

Field experiments were conducted at three locations within the pea production area of southeastern Washington and northeastern Oregon, USA, in 1986 and 1987. Expected annual precipitations at these sites were 400, 480 and 560 mm. Sixty percent of the precipitation occurs

\textsuperscript{3}Mention of a specific product does not constitute a recommendation by the U.S. Department of Agriculture and does not imply its approval to the exclusion of other suitable products.
during the months of November-March. A silt loam soil was present at all three sites and varied in depth from 1.5 to greater than 3 m. Soil characteristics and annual precipitations for these sites are shown in Table I. Peas had been grown in rotation with winter wheat for over 20 years at each site.

Four tillage treatments, which consisted of combinations of Paraplow tillage, no Paraplow tillage, moldboard plowing and chisel plowing (10 cm wide twisted shovel) were replicated four times in plots 14 by 21 m. Paraplow tillage 33 to 38 cm deep was accomplished in late summer after pea harvest when the soil water content in the top meter was generally less than 0.15 m$^3$/m$^3$. After a wheat crop wheat stubble, which ranged from 6200 to 10000 kg/ha was shredded with a rotary mower in August, immediately after harvest. Chisel or moldboard plowing followed in September to create two different distributions of crop residue within the soil profile. Secondary tillage was accomplished in late March and early April. The processing pea cultivar 'OSU 605' was seeded at 225 kg/ha on April 1, 15 and May 1 at sites 1, 2 and 3, respectively. A double disc drill was used with rows 18 cm apart.

Vertical soil cores 7 cm in diameter 30 cm long were taken to determine crop residue distribution in May. These cores were sectioned in 2 cm increments and wet sieved. The dry mass of crop residue particles retained on a number 35 sieve (0.407 mm opening) per g of air dry soil was defined as coarse organic matter. The line transect method was used to determine the percent of ground covered with crop residue.

The severity of tillage pans and the extent of their disruption by Paraplow tillage was determined with a hand-operated cone penetrometer. The cone had a 30 degree angle and a 13 mm diameter base. Five penetrations were made in each plot midway through the growing season. Soil water status was monitored with a neutron meter biweekly during the growing season. Green peas were harvested at a tenderometer reading of 90-100. An area of approximately 3 by 21 m was harvested and yields were adjusted to equal an 100 tenderometer reading (Pumphrey et al., 1975).

RESULTS

Chisel plowing followed by secondary tillages and seeding concentrated wheat crop residue in the top 10 cm of the soil profile (Fig. 1). Moldboard plowing followed by similar secondary tillages created bands or ribbons of residue from 10 to 25 cm below the soil surface (Fig. 1). The system with chisel plowing resulted in 30% ground cover compared to 6% for the system with moldboard plowing (Table II). Increased surface residue in the chisel plow system compared to the moldboard plow system did not significantly alter the mean monthly 5 cm soil temperature or soil water status throughout the growing season. Chisel plowing did not significantly (5% level) influence stand establishment, fresh pea yield or plant biomass (Table II).

Paraplow tillage ruptured the tillage pan that had developed over the years. Twenty months after Paraplow tillage, which was midseason of the pea crop, the loosening effect of Paraplow tillage still could be detected with a cone penetrometer (Fig. 2). Paraplow tillage did not significantly effect soil water status, plant establishment, fresh pea yield or plant biomass (Table III).
DISCUSSION

The chisel plow system increased wheat plant residue on the soil surface compared to the moldboard plow based system but this increased residue did not significantly change the soil water status or soil temperature. Using the methods of Van Doren and Allmaras (1978), the predicted difference in 5 cm soil temperature between the moldboard and chisel plowed plots would be less than 1 C degree. This small difference in predicted temperature was consistent with the findings of this research. The overwinter soil water storage was the same for soil tilled by either chisel or moldboard plowing because infiltration rates and surface storage capacities associated with both were adequate to prevent water from running off of the plots. The soil water content and temperature were not significantly different for chisel and moldboard plowing and consequently the growth and yield of peas were not significantly different for the two tillage systems. Establishing adequate stands with a standard double disk drill in fields with 30% or more of the surface covered with crop residue is difficult. Crop residue is pushed into the seed furrow below the disks and opener penetration is often inadequate.

Paraplow tillage 33 to 38 cm deep after pea harvest, when the soil water content was low, fractured the tillage pan. The effect of the Paraplow tillage was short lived and the tillage pan had partially reformed in less than two years. Although the effect of deep tillage could be detected in some fields 20 months later, consolidation forces due to traffic, tillage, weathering and chemical bonding had returned the soil profile almost to its original compacted state. The decreased penetrometer resistance in the soil loosened by Paraplow tillage compared to no Paraplow tillage did not produce a different soil water extraction pattern in the top 90 cm. Ehlers et al. (1983) found the limiting penetration resistance for root growth of oats was over 20% less for tilled soil as compared to untilled soil. The difference was apparently due to channels established in the soil profile from old roots and earthworms. The maximum difference in soil resistance to penetration for Paraplow tillage and no Paraplow tillage was less than 20% (Fig. 2). Therefore any advantage of loosening the soil by paraplowing may have been negated by breaking the natural channels through the tillage pan which had been established over many years by worms and plant roots. Breaking the tillage pan in these fields did not change the amount of water stored in the soil profile over winter. Pea growth and yield were not increased by breaking the tillage pan by Paraplow tillage. Pikul and Allmaras (1986) showed that the saturated hydraulic conductivity through the plow pan could be from 3 to 10 times lower than through the surface in a Haploxeroll soil. It is possible in fields with steeper slopes or years with more intense precipitation patterns that the water infiltration through the tillage pan could limit water storage. In such cases, more water would be stored in soil profiles where the tillage pan had been fractured. Crops would benefit from the additional soil water and higher yields would be expected.

CONCLUSIONS

In eastern Washington and Oregon where peas have been grown in rotation with cereal crops for over 20 years on Haploxeroll soils, it can be concluded from these results: 1) Tillage pans are present in some of these fields between 20 and 35 cm, 2) Paraplow tillage 33 to 38 cm deep fractured the pans but they reformed at least partially and in some cases completely in 20 months, 3) Paraplow tillage did not significantly
change the amount of soil water stored during the winter months or the soil water extraction pattern during the growing season, 4) Paraplow tillage did not significantly influence stand establishment, biomass or fresh pea yield, 5) chisel plowing concentrated crop residue in the top 10 cm and on the surface while moldboard plowing placed the residue in bands between 10 and 25 cm. The increased surface residue in the chisel plowing system did not significantly alter the soil temperature or soil water content, and 6) pea stands, biomass and fresh pea yield were not significantly changed by chisel plowing instead of moldboard plowing. Deep tillage is not justified but primary tillage can be altered from moldboard plow based production systems to methods that place crop residue on and near the soil surface for soil erosion control without sacrificing fresh pea yields.

REFERENCES


TABLE I. Soil characteristics and annual precipitation.

<table>
<thead>
<tr>
<th>Site</th>
<th>Soil identification</th>
<th>Soil depth (m)</th>
<th>Slope (%)</th>
<th>Average annual precipitation (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Walla Walla silt loam (coarse-silty, mixed, mesic Typic Haploxerolls)</td>
<td>&gt; 3</td>
<td>1-2</td>
<td>400</td>
</tr>
<tr>
<td>2</td>
<td>Palouse silt loam (fine-silty, mixed, mesic, Pachic Ultic Haploxerolls)</td>
<td>2</td>
<td>9-13</td>
<td>560</td>
</tr>
<tr>
<td>3</td>
<td>Athena silt loam (fine-silty, mixed, mesic Pachic Haploxerolls)</td>
<td>1.5</td>
<td>3</td>
<td>480</td>
</tr>
</tbody>
</table>

TABLE II. Influence of primary tillage on soil water status, ground cover and pea growth.

<table>
<thead>
<tr>
<th>Primary tillage</th>
<th>Soil water* (M³/M²)</th>
<th>Ground cover (%)</th>
<th>Plant establishment (plants/M²)</th>
<th>Fresh pea yield (kg/ha)</th>
<th>Biomass (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moldboard plowed</td>
<td>.27</td>
<td>6 A**</td>
<td>92 A</td>
<td>3120 A</td>
<td>4432 A</td>
</tr>
<tr>
<td>Chisel plowed</td>
<td>.27</td>
<td>30 B</td>
<td>89 A</td>
<td>3243 A</td>
<td>4515 A</td>
</tr>
</tbody>
</table>

* Soil water in the top 90 cm 30 days after seeding.
** Means within a column followed by the same letter are not significantly different at the 5% level.

TABLE III. Influence of Paraplow tillage 33 to 38 cm deep on soil water status and pea growth.

<table>
<thead>
<tr>
<th>Deep tillage</th>
<th>Soil water* (M³/M²)</th>
<th>Stand (Plants/M²)</th>
<th>Fresh pea yield (kg/ha)</th>
<th>Biomass (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paraplow</td>
<td>.27</td>
<td>91 A**</td>
<td>3130 A</td>
<td>4508 A</td>
</tr>
<tr>
<td>None</td>
<td>.27</td>
<td>90 A</td>
<td>3232 A</td>
<td>4439 A</td>
</tr>
</tbody>
</table>

* Soil water in the top 90 cm 30 days after seeding.
** Means within a column followed by the same letter are not significantly different at the 5% level.
Fig. 1 Effect of primary tillage on distribution of coarse organic matter in the soil profile (adapted from Wilkins et al., 1987).

Fig. 2 Cone penetrometer resistance profile 20 months after Paraplow tillage 38 cm deep (adapted from Wilkins et al., 1986).
PHYSICAL PROPERTIES OF TWO STRUCTURALLY SENSITIVE SOILS AND THEIR EFFECTS ON CROP GROWTH

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2Institute of Horticultural Research, Wellesbourne, Warwick CV35 9EF (present address: ICI Fertilizers, Jealott's Hill Research Station, Bracknell RG12 6EY).

ABSTRACT

Soil physical properties and crop growth on two sites for which there is a documented history of systematic differences in crop yield were compared. Both soils were structurally weak sandy loams which slumped after ploughing so that their bulk densities did not differ from the subsoil. Differences in root and crop growth are related to field measurements of bulk density and penetrometer resistance, to laboratory needle penetrometer resistance, and to rooting density. On the site with better root and crop growth there were structural cracks, generated by root growth in the slumped plough layer, which did not exist on the other site.

INTRODUCTION

Some structurally unstable soils are liable to slump after cultivation and can set hard without structural development on drying. This 'hard-setting' behaviour can result in physical impedance to root growth even within previously cultivated layers of soil (Mullins et al., 1987). On two sites at the Institute of Horticultural Research, Wellesbourne, there is a documented history of systematic differences in crop yields despite the soils on both sites being of the same (Wick) soil series and the incorporation of large quantities of fertilizer (Costigan et al., 1983). Although these authors provide strong evidence that the restricted growth results from the inability of the poorer site to supply sufficient potassium to the crop in the early stages of growth, our observations suggested that these soils might be hard-setting but to very different extents. Thus differences in soil physical properties could then be an additional source of variation in growth. We have tried to test this hypothesis by attempting to quantify two features (slumping and physical impedance to root growth) related to hard-setting behaviour. A more detailed description of this work can be found in Young (1987).
MATERIALS AND METHODS

The two sites, Plum Orchard (PO) and Big Ground (BG) were ploughed to 27 cm on 25/10/85. BG had been in cereals for many years previously whereas PO had been under continuous pasture prior to 1975 and subsequently planted to a variety of crops. The sites were rotavated to 12 cm and fertilizer (150 kg N/ha, 60 kg P₂O₅/ha and 150 kg K₂O/ha) was applied on 22/5/86. Cabbage plants (cv. Stonehead) were transplanted into duplicate 1½ x 10 m plots on each site on 26/5/86 and at the same time a solution of starter fertilizer was poured around the roots of each plant.

Twenty penetrometer measurements were made with a 'Bush' recording penetrometer in each plot on four separate occasions during the growth of the plants. Dry bulk density was measured using a high resolution gamma-ray probe (Henshall and Campbell, 1983) immediately after transplanting and 5 weeks later. The crop was sampled at 5 weeks (on 9/7/86) and at harvest on 21/8/86 for measurement of plant dry matter and chemical analysis. Root counts were also made down two profiles on each site at 5 weeks.

RESULTS

The particle size distributions for both sites did not differ beyond the limits of experimental accuracy but PO soil contained about 0.6% more organic matter than BG (Table I). Mica dominated the clay mineralogy of both soils but PO contained some chlorite and chlorite-vermiculite interstratified minerals whilst BG contained vermiculite but little if any chlorite.

Table I. Particle size analysis (% mineral matter), and organic matter content

<table>
<thead>
<tr>
<th>Soil</th>
<th>Particle size distribution (μm)</th>
<th>Organic matter (% w/w)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2000-200</td>
<td>200-60</td>
</tr>
<tr>
<td>Big (12-16 cm)</td>
<td>46</td>
<td>22</td>
</tr>
<tr>
<td>Ground (30-34 cm)</td>
<td>45</td>
<td>23</td>
</tr>
<tr>
<td>Plum (12-16 cm)</td>
<td>49</td>
<td>20</td>
</tr>
<tr>
<td>Orchard (30-34 cm)</td>
<td>47</td>
<td>21</td>
</tr>
</tbody>
</table>

Figure 1 is a typical example of the variation of dry bulk density with depth. In four sets of measurements taken over 2 years, BG consistently had a slightly greater bulk density (by ca. 0.1 Mg/m³) below the rotavated depth than PO. Penetrometer results on two occasions are given Table II.
Table II. Mean penetration resistance (MPa) versus depth in the rotavated (R), plough layer (P) and subsoil (S). Standard errors were 10% or less of the means.

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Three days after transplanting (29/5/86)</th>
<th>Five weeks after transplanting (7-9/7/86)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Plum Orchard</td>
<td>Big Ground</td>
</tr>
<tr>
<td>7</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>14</td>
<td>0.8</td>
<td>1.1</td>
</tr>
<tr>
<td>21</td>
<td>0.9</td>
<td>1.1</td>
</tr>
<tr>
<td>28</td>
<td>1.0</td>
<td>1.4</td>
</tr>
<tr>
<td>35</td>
<td>1.9</td>
<td>1.7</td>
</tr>
<tr>
<td>42</td>
<td>2.5</td>
<td>1.7</td>
</tr>
<tr>
<td>49</td>
<td>2.1</td>
<td>1.9</td>
</tr>
</tbody>
</table>

(a) 28% of total readings at this depth were off scale (i.e. >6 MPa).
(b) 75% of total readings at this depth were off scale.
(c) The soil was impenetrable at this depth.

Dry bulk density (Mg/m³)

![Graph showing dry bulk density](image)

Fig. 1 Mean dry bulk density
At 5 weeks the average dry weight of a cabbage was significantly heavier ($P < 0.05$) on PO (21g/plant) than on BG (12g/plant). By harvest however, the corresponding values were 77 and 68g/plant and there was no longer a significant difference between the two sites. Plant concentrations of K and P at 5 weeks were significantly lower in BG (3.27% K, 0.39% P) than in PO (3.64% K, 0.51% P) but the differences were relatively small. By final harvest there were no significant differences in plant nutrient concentration between BG (3.80 K, 0.44% P) and PO (3.81% K, 0.41% P). There was a sharp contrast in rooting density between the two sites by 5 weeks after transplanting (Table III).

Table III. Rooting density (cm$^{-2}$) of cabbage roots 5 weeks after transplanting, one standard error is given in brackets

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Plum Orchard</th>
<th>Big Ground</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-10</td>
<td>0.57 (0.07)</td>
<td>0.35 (0.02)</td>
</tr>
<tr>
<td>10-20</td>
<td>0.44 (0.05)</td>
<td>0.34 (0.04)</td>
</tr>
<tr>
<td>20-30</td>
<td>0.29 (0.05)</td>
<td>0.07 (0.02)</td>
</tr>
<tr>
<td>30-40</td>
<td>0.20 (0.04)</td>
<td>0</td>
</tr>
<tr>
<td>40-50</td>
<td>0.16 (0.04)</td>
<td>0</td>
</tr>
</tbody>
</table>

DISCUSSION

Ploughing is usually found to decrease bulk density but at both sites there was no detectable difference between subsoil bulk density and that of the plough layer which implies that slumping had occurred after ploughing. From our own observations, that the moist soil dug for root inspection pits slumped back to the same level surface when replaced, it is clear that this slumping can actually occur during ploughing if the soil is sufficiently moist.

When examined 5 weeks after transplanting, both the plough layer and the subsoil in BG were observed to be structureless and roots were growing in a homogeneous mass of soil. Under these circumstances it is reasonable to use penetrometer resistance as a measure of the physical impedance which roots will encounter. It is clear from other studies (Taylor and Ratliff, 1969; Greacen et al., 1969) that a penetrometer resistance of more than 6 MPa is sufficient to seriously slow down or halt root growth while a resistance of 2 MPa should cause a substantial reduction in root growth rate compared to unimpeded soil conditions. Maize roots grown into undisturbed cores, which were taken from the plough layer on both sites five weeks after transplanting and equilibrated at a matric potential of -10 kPa, were found to grow about 30% more slowly than those in an unimpeded control (Bengough and
Mullins, 1988). These cores had a penetration resistance (measured with a 1 mm diameter core) of about 2MPa. Thus it can be concluded that, even when the soil was close to field capacity, physical impedance reduced the rate of root growth in the plough layer and subsoil on both sites. A comparison of Tables II and III indicates that as the soil on BG was dried by roots its resistance probably rose to the point at which no further root growth within the lower part of the plough layer and subsoil was possible.

Penetration resistance varied with moisture content in a similar manner on both sites but, when measuring rooting density at 5 weeks, at least half of the roots in the plough layer and subsoil of PO were seen to be growing down fine structural cracks. This soil did not contain visible cracks when the cabbages were planted and it is reasonable to suggest that, at least in the slumped plough layer, root growth and structural cracking occurred simultaneously. At any event, it is clear that because of the structural development the penetrometer results at 5 weeks do not give a reliable indication of the ease of root growth.

In a previous study it was inferred from the absence of any marked differences in bulk density and penetration resistance between the two sites that differences in resistance to root penetration were unlikely to provide the explanation for early differences in the rate of crop growth. It was then argued that restricted growth resulted from the inability of the poorer site to supply sufficient potassium and possibly phosphorus to the crop (Costigan et al., 1983). Our results support the latter proposition but now provide evidence of a greater structural development on the better site which should allow easier root growth and a more extensive rooting system. Thus there is now evidence that differences in both soil physical and chemical properties can contribute and probably interact to give the observed differences in growth on the two sites.

CONCLUSIONS

(1) On both sites the soils slumped after ploughing.

(2) Root growth on the poorer site was severely restricted by physical impedance.

(3) On the better site soil structural development enabled the development of a much better root system.

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